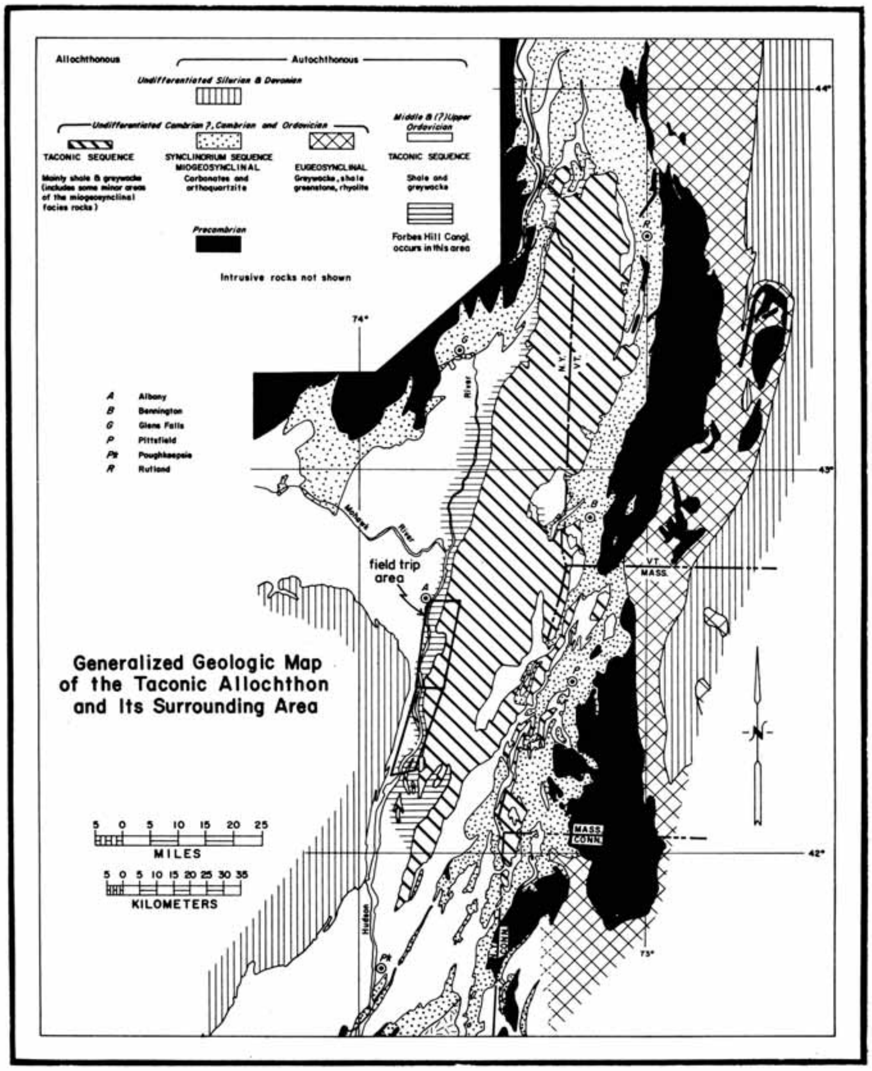
DUKE GEOLOGICAL LABORATORY

Web: www.dukelabs.com
E-Mail: CharlesM@dukelabs.com

TRIPS ON THE ROCKS

Guide 07: The Taconic Range of Eastern New York

Trip 08: 21/22 October 1989; Trip 22: 09/10 May 1992



Field Trip Notes by:

Charles Merguerian and John E. Sanders

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INTRODUCTION

This two-day field trip, a double-or-nothing category in our On-The-Rocks field trip series, is intended to introduce participants to an investigation into the sequence stratigraphy, age, structural configuration, and plate-tectonic history of the rocks underlying the Taconic Range of eastern New York State. Our main topic will be the Taconic "problem," which embraces a group of subjects including the stratigraphic relationships of the Cambro-Ordovician marine sedimentary strata and what is meant by the "Taconic orogeny." As we shall see, the name of the game is overthrusts! But, what game? What overthrusts?

Initially the geologists who studied the Taconic territory wondered how the predominantly pelitic terrigenous rocks (mostly slates, phyllites, and schists) underlying the low, rolling hills forming the Taconic Range were related to the Cambro-Ordovician carbonate rocks that underlie large parts of the lowlands situated east, north, and west of the Taconic Range. After great debates about the age relationships, a consensus developed that the pelitic terrigenous rocks had been displaced westward from their former depositional setting perhaps 100 km or so east of where they are now found. The displaced pelitic strata thus were designated as the Taconic allochthon.

The interpretation that such tectonically "weak" materials had experienced such an enormous displacement by overthrusting prompted skepticism in the minds of a few geologists. They sought evidence at the contact of the pelites and the carbonates. They anticipated finding mylonite or some contrast in structural fabric between the pelites and carbonates. Finding none, they asked: "Where is the overthrust?" Other geologists examined the pelites/carbonates contact and concluded they had been looking at a surface of unconformity. Still others proposed that the "weak" stuff had not been overthrust in the classical sense at all, but rather had been displaced by the mechanism of large-scale gravity sliding of unconsolidated sediments down a submarine slope inclined westward. Given that the initial submarine slope had been eastward, this scheme required enormous uplift to reverse the slope from east to west. "No problem," they said, pointing to the regional arch of the Green Mountains-Berkshires-Housatonic Highlands. "Yes problem," contended others; the Taconic pelites came from east of this regional arch. Therefore, arch uplift should have displaced Taconic sediments eastward, not westward. JES even argued that the age of the elevation of the regional arch was post-Newark sediments (i. e., Mesozoic) and thus much too late to have influenced the Ordovician displacement of Taconic sediments one way or the other.

Next came the question of "hard-rock" vs. "soft-rock" Taconic overthrusts and the chronology of events in the tectonic parade known as the Taconic Orogeny. As originally conceived, this orogeny was touted as the event that ended the Ordovician Period. Its geological "calling card" was supposed to be an angular discordance between Ordovician strata and Silurian strata. But, other tectonic events included metamorphism and emplacement of plutons.

When the age of the displacement of the Taconic allochthon had been determined as Mid-Ordovician, grumbling arose about how the allochthon and the "orogeny" were associated. Along about now, plate tectonics enters the scene. Given that development, the race was on to explain mountain chains and orogeny in terms of plate convergence, subduction zones, offscraping of sea-floor sediments and the forming of mélanges. Assertions about how the Taconic orogeny fitted into the plate-tectonics view of continental margins and mountain belts, which were published in an abstract of a paper given at the annual meeting of the Geological Society of America, have become repeated so many times that they have attained the status of received wisdom.

Research by CM and associates in western Connecticut has shown that many "hard-rock" tectonic events preceded the emplacement of the Taconic allochthon. Now, JES is studying the subject of pre-Taconic-allochthon large-scale overthrusts breaking loose inboard of the former shelf edge. On some of these overthrusts, thin slices of Precambrian basement rocks with a cover sequence composed of Cambro-Ordovician carbonate rocks and overlying mid-Ordovician shales, have overridden Ordovician shales. No matter how all this turns out, we hope that our struggles with these problems give you some new insights into some classic Appalachian geologic features.

We will spend the first day examining the remnants of a vast overthrust sheet of Proterozoic rocks consisting of varying gneisses, mostly felsic and graphitic. You will feast your eyes on the Proterozoic-Lower Cambrian nonconformity and trace the Sauk Sequence (Cambrian and Early Ordovician), the predominantly dolomitic deposits of a shallow, tropical carbonate shelf on a former passive continental-margin upward in time into the strata of the overlying Tippecanoe Sequence, a sucession of shallow-water clastics and carbonates plus a peek at some Middle Ordovician turbidites deposited in a foreland basin that supplanted the former carbonate shelf when the big overthrusts began to move. Thus, during the course of the day, we will travel through time and into structurally higher and higher rock sequences. Your fingertips will sense the Earth's Ordovician pulse and your eyes examine the direct- and indirect effects of the Taconic orogeny. Day One will end with an in-the-field, On-The-Rocks discussion concerning the genesis of unique rocks found on the east side of the Hudson River in Poughkeepsie, New York.

Day Two will begin with an instructional visit to a fantastic sequence of graywackes (Middle Ordovician flysch) of the Tippecanoe Sequence, the deposits of the foreland basin, exposed on the west side of the Hudson River in Highland, New York. From there, we will travel eastward and then northward to examine the thrust slices of the Taconic Sequence that underlie the Taconic Range in New York and Massachusetts (if only for a footstep!), examine and touch a second unconformity (the Taconic unconformity), and examine and compare rocks of the Taconic Sequence that have been more highly metamorphosed than we have seen so far, rocks of comparable metamorphic grade with those in southeastern New York.

Our stops (albeit only a pull-over one) begin at an outcrop of the contact between the base of the Cambrian (Poughquag Quartzite) and Precambrian gneiss exposed on I-84 where the eastbound ramp enters from Union Avenue, west of Newburgh. On the N side of I-84, one can see the Precambrian gneisses in fault contact with the Middle Ordovician shales of the Tippecanoe Sequence. Consult Table 1 in conjunction with the following discussion. It is a time chart showing geologic time subdivisions used on the bedrock maps herein, with estimates of numbers of years for their boundaries and a list of some important local geologic events. Table 2 summarizes the major local geologic units (stratigraphy) in terms of layers designated by Roman numerals and Sequences.

GEOLOGIC BACKGROUND

Under this heading, we discuss the physiographic setting of the territory we shall visit, highlighting the Taconic range; summarize the bedrock units in terms of Sequences and show how the sequence approach unsnarls that long-standing "rat's nest" of New York geology--the Taconic controversy; and the briefly mention the glacial deposits of the field-trip route.

PHYSIOGRAPHIC SETTING

Our trip takes us into a critical sector of the Appalachian Range in eastern New York State. We begin in the Manhattan Prong of the New England Upland, drive across the Newark Lowland near its northeastern end, go over the Hudson Highlands, traverse a small piece of the northeast end of the Reading Prong, pass Schunemunk Mountain, and then enter the Appalachian Great Valley. On Day Two, we finally reach the Taconic Range, which is a distinctive stretch of country lying within what would otherwise be the Appalachian Valley and Ridge province.

Manhattan Prong

The Appalachians Highlands province designates the high region in the median part of the Appalachian chain. In the northern Appalachians, this continuous highland region is named the New England uplands province. In western Connecticut-southeastern New York, this highland province has been divided into two "prongs:" the Manhattan Prong on the southeast and the Reading Prong on the northwest.

The Manhattan Prong reaches from western Connecticut southwestward across Westchester County to parts of New York City, including all of the Bronx, extreme western Queens, all of Manhattan, and the part of Staten Island around Todt Hill; it also includes a small area in New Jersey, a narrow strip reaching from Hoboken south to Jersey City.

The morphology of the Manhattan Prong is a somewhat subdued valley-and-ridge type in that low, rounded, elongate ridges underlain by schist or gneiss are separated by linear valleys underlain by marble. The underlying bedrock consists chiefly of metamorphic rocks of Precambrian and Early Paleozoic ages. Within this metamorphic complex are a few bodies of igneous rocks, some of which have also been metamorphosed and some of which have not been metamorphosed. Some of these bodies of igneous rock form irregular hills.

According to CM's new interpretation, much of the Manhattan Schist is nothing but the Taconic allochthon in metamorphic disguise. One of the key objectives of this Taconic field trip is to show you what we think are the protoliths of the metamorphic rocks underlying the Manhattan Prong.

Newark Lowland

The Newark Lowland is a subprovince in which "lowland" is an approrpiate term only when considered on a regional scale. Locally, parts of this "lowland" form ridges that are higher than the adjoining "uplands." For example, the wall-like Palisades Ridge extends along the west side of the Hudson River from Haverstraw, Rockland County, NY, to Hoboken, NJ; and the altitudes on top of the three Watchung ridges are as much as 885 ft at High Mountain on Preakness Mountain or 620 feet on Second Watchung Mountain in West Orange, NJ) 536 ft at Garrett Mountain (1st Watchung in Paterson, NJ; or 640 ft on Orange Mountain, West Orange, NJ).

The associated Newark sedimentary strata, particularly the shales, do underlie lowlands. But even some of the Newark strata form hills: the coarser strata, such as sandstones and conglomerates, and the tough Lockatong argillite are examples.

Hudson Highlands

The Hudson Highlands refers to the massive, rounded peaks of mostly granitic rock that forms the highest territory between the generally lower Manhattan Prong or Newark Lowland on the southeast and the Reading Prong or Appalachian Great Valley on the northwest. Bear Mountain is a typical example.

Reading Prong

The Reading Prong designates that part of the Appalachian Highlands northwest of the Newark Basin lowland. It includes the so-called Hudson/New Jersey Highlands.

Our trip route takes us across a sector of the Reading Prong where the Precambrian and Paleozoic rocks have been broken and juxtaposed by northeast-southwest-trending faults some of which are demonstrably of mid-Jurassic (i. e., post-Newark strata) age. In addition, Isachsen (1963) proposed the concept of the Reading Prong klippe. By that, he meant that the Precambrian rocks have been thrust over the Paleozoic rocks on one or more great low-angle faults.

One particularly distinctive sector of the Reading Prong in southeastern New York is the Monroe block, a bit of country like the Canadian Shield. In both, glaciated Precambrian bedrock forms low, rolling hills. In some places, the Precambrian rocks are nonconformably overlain by the Hardyston/Poughquag Quartzites at the base of the Sauk carbonates. Elsewhere, as in the structure named the Thruway Graben (Jaffe and Jaffe, 1973), the Sauk Sequence carbonates underlie an elongate valley that is shut in on all sides by Precambrian rocks. Whether this lowland followed by the Thruway is really a graben or not needs to be reevaluated in light of the information supporting Isachsen's interpretation of the extensive overthrusting of Precambrian rocks above the Paleozoic. Two alternative interpretations to the idea of a graben need to be checked: (1) is the supposed graben really a horst? or (2) is the supposed graben a fenster (or window)?

A horst is an elongate fault-block feature that differs from a graben only in the sense of fault motion. A graben is bordered along normal faults that are relatively downwthrown in the middle and upthrown on the sides. A horst is a block bordered by faults that are relatively upthrown in the middle and downthrown on the sides. The graben interpretation was proposed on the basis that the only Precambrian rocks around are down below (obviously; Precambrian is older and therefore underlies the Paleozoic rocks). But, if the local Precambrian rocks are part of an overthrust sheet, then one can derive Precambrian rocks not only from down below but also from up above. Precambrian rocks from above the overthrust could have been faulted down against the Paleozoic rocks. In that case, the Paleozoic rocks would form a relatively elevated block, i. e., a horst. (As a geologist, one would never like to be referred to as someone that didn't known his horst from his graben.)

A fenster is a place where the rocks above an overthrust have been locally eroded so that the rocks beneath the overthrust become exposed. The "hole" in the overthrust rocks has been termed a fenster (in German; used in the English-language geological jargon by the literal translation "window"). The same morphologic appearance could be caused by a graben, a horst, or a fenster; the critical evidence for determining the correct interpretation would come from the relationships between the Precambrian rocks and the Paleozoic rocks.

If the feature is a graben, as advertised, then the Paleozoic rocks form an elongate narrow block that has been downfaulted into the Precambrian rocks (older, and therefore presumably underlying the Paleozoic rocks). The Paleozoic rocks of the putative graben would end abruptly at the steep marginal faults. All around and even down below would be Precambrian rocks.

If the feature is a horst, then the Precambrian rocks on the sides have been relatively downdropped on steep faults.

By contrast, if the feature is a fenster, then the Paleozoic rocks would extend beneath the Precambrian rocks; the fault between the Precambrian rocks and the Paleozoic rocks would be a low-angle (even horizontal) overthrust.

Schunemunk Mountain

Schunemunk Mountain is a prominent high area lying NW of the New York Thruway and NE of Route 17 that terminates abruptly at Moodner Kill. Schunemunk Mountain is the northeasternmost part of the Schunemunk-Bellvale-Green Pond belt of downfaulted Silurian and Devonian strata that is bordered on all sides by Cambro-Ordovician strata and/or Precambrian basement rocks of the Reading Prong.

Appalachian Great Valley

The Appalachian Great Valley is one of the remarkable physiographic subdivisions of the Appalachians. The morphology of the Great Valley regionally is a lowland, yet its rocks are geologically mountain rocks. As in the Newark "lowland," however, within the Great Valley are scattered prominent ridges.

The Taconic Range

The Taconic range forms a series of rolling hills stretching for roughly 240 km from near Poughkeepsie, New York to north of Rutland, Vermont (Figure 1). At their widest point the Taconics are 40 km across and therefore form an impressive, if not somewhat topographically subdued, physiographic province nestled east of the Devonian Catskills and Precambrian Adirondack mountains and west of the Berkshire and Green Mountain Precambrian massifs (Figure 1). The Taconics are an allochthonous mountain range (unrooted) consisting of the Taconic Sequence, Lower Paleozoic deep-water, mostly fine-textured terrigenous rocks that have been structurally displaced so far to the west that they now lie upon the strata of the Sauk Sequence and lower part of the overlying Tippecanoe Sequence. The "Taconic Problem," as it has been known since the early 1900s, entails questions about the ages and paleogeographic relationships of the Taconic Sequence and the "Taconic look-alike" parts of the Tippecanoe Sequence and the structural relationships of both to the Sauk Sequence carbonates. In short, where did the strata of the "Taconic Sequence" come from and how did they get where we see them today? Details of the "Taconic Problem" are discussed below.

Based on topographic expression, metamorphic grade, relative structural position, and stratigraphy of the underlying rocks, the Taconics are subdivided into an eastern belt (high Taconics) and a western belt (low Taconics). The term "high" applies in nearly all possible geologic senses. The land elevations of the high Taconics are higher, the metamorphic grade of the underlying rocks is higher, and and the structural positions of the Taconic rocks are higher than are comparable attributes in areas situated farther west in the low Taconics. Zen (1967) suggested that the Taconic range consists of six or seven discrete structural slices. (See cross section on cover and Figure 2.) The westernmost exposures of the Taconic allochthon (the Sunset Lake, Giddings Brook, Chatham, and Rensselaer slices) constitute the low Taconics. The Dorset Mountain slice in Massachusetts (=Everett slice in New York) constitutes the high Taconics.

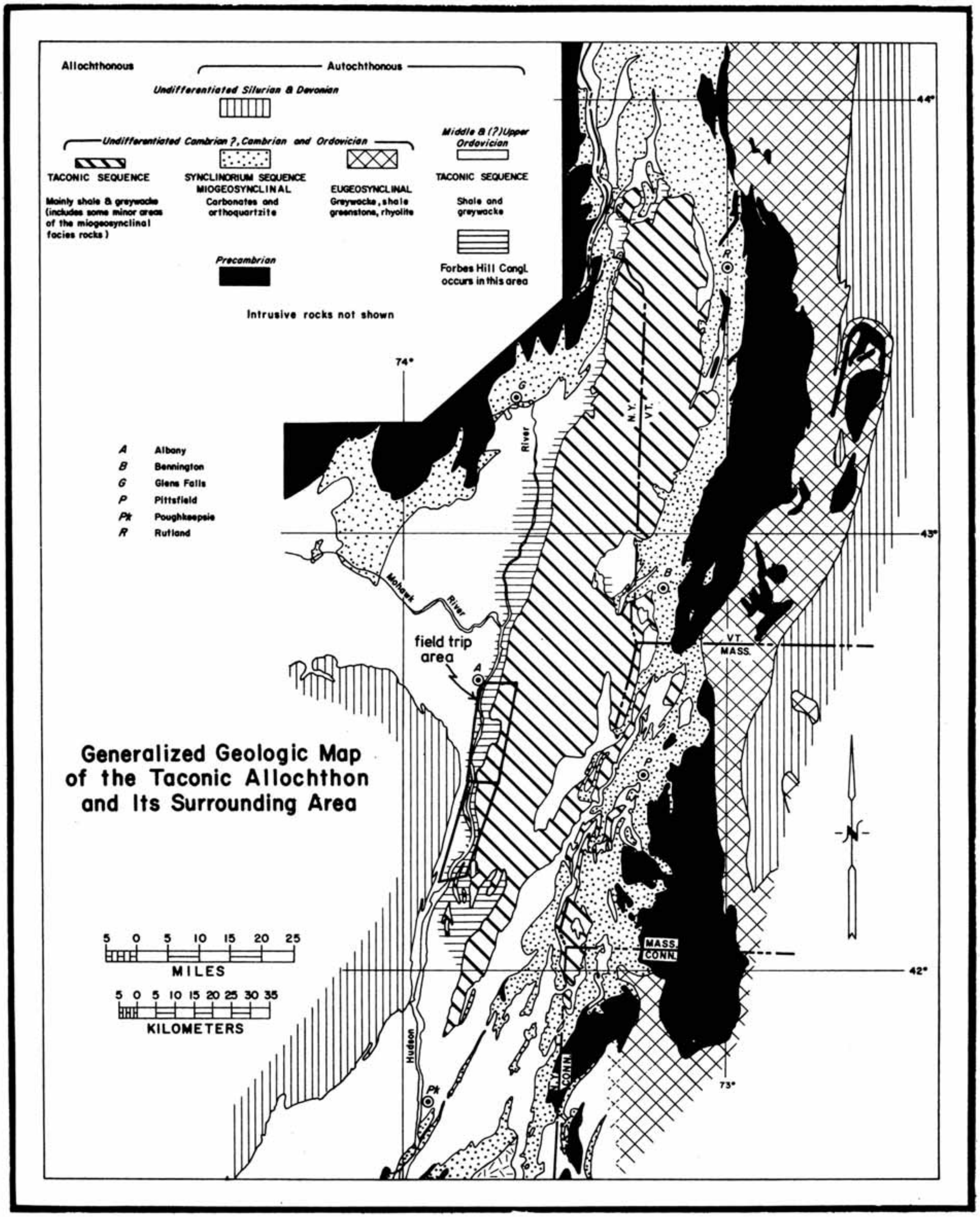


Figure 1 - Generalized geologic map of the Taconic allochthon from Bird and Dewey, 1975. Trace of geologic cross-section on cover shown through Albany, New York.

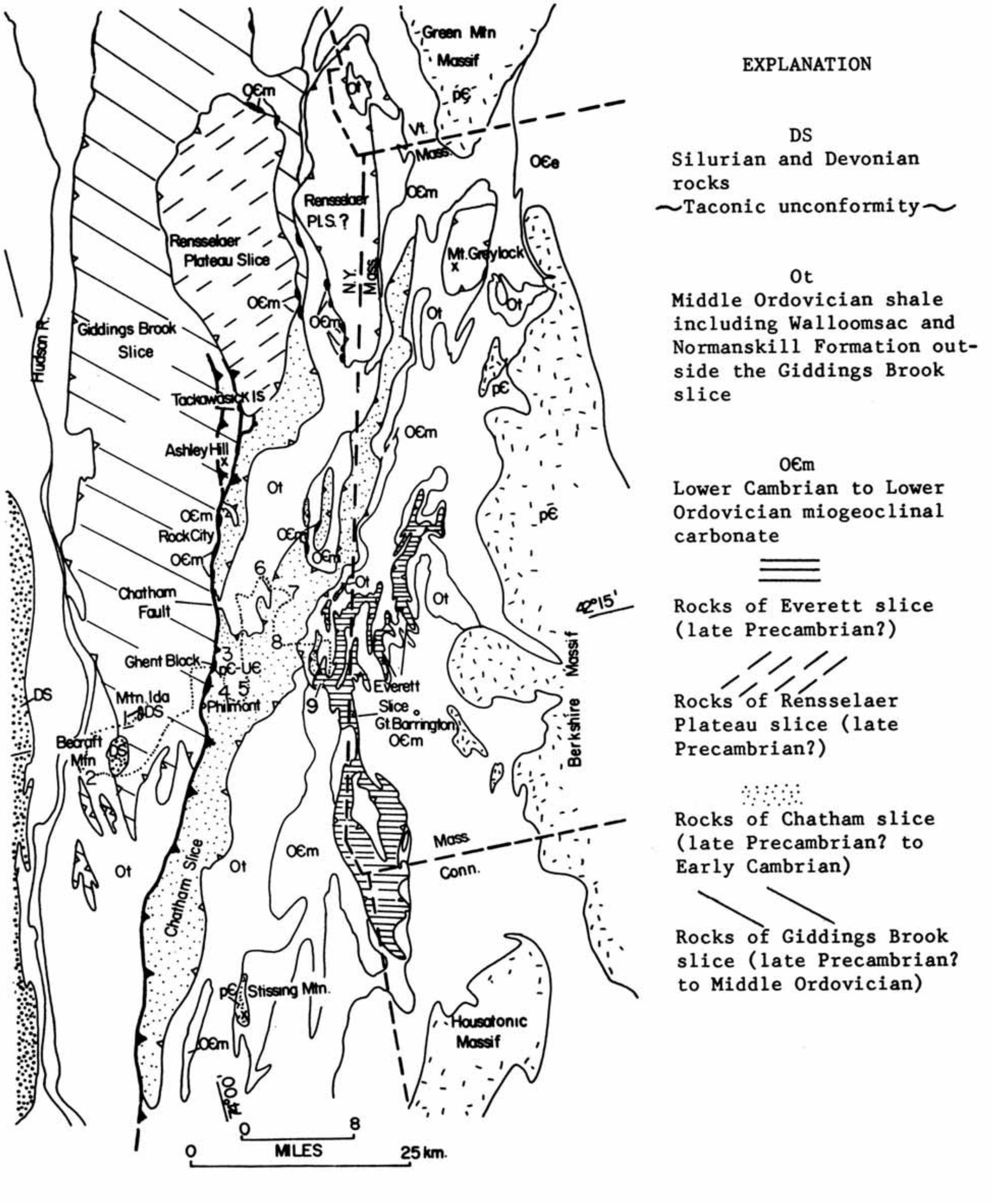


Figure 2 - Detailed regional geologic map showing various slices of the Taconic allochthon from Ratcliffe and others, 1975.

The Taconic Sequence consists of a vast sequence of slate, siltstone, graywacke, quartzite, and ribbon limestone (Figure 3). Detailed stratigraphic- and paleontologic studies have offered great control on the timing of the emplacement of the Taconic allochthons (Figure 4). As originally discovered by Ruedemann (1901a, b), the fossils found amidst the dark-colored matrix of the Rysedorph Hill Conglomerate date the emplacement of the Taconic allochthon as Medial Ordovician in age. Modern studies indicate that this occurred within zone 13 of the graptolite zones found within the Normanskill Formation (Figure 5). Details on these stratigraphic arguments are presented below under the headings "Layer II" and "The Taconic Problem".

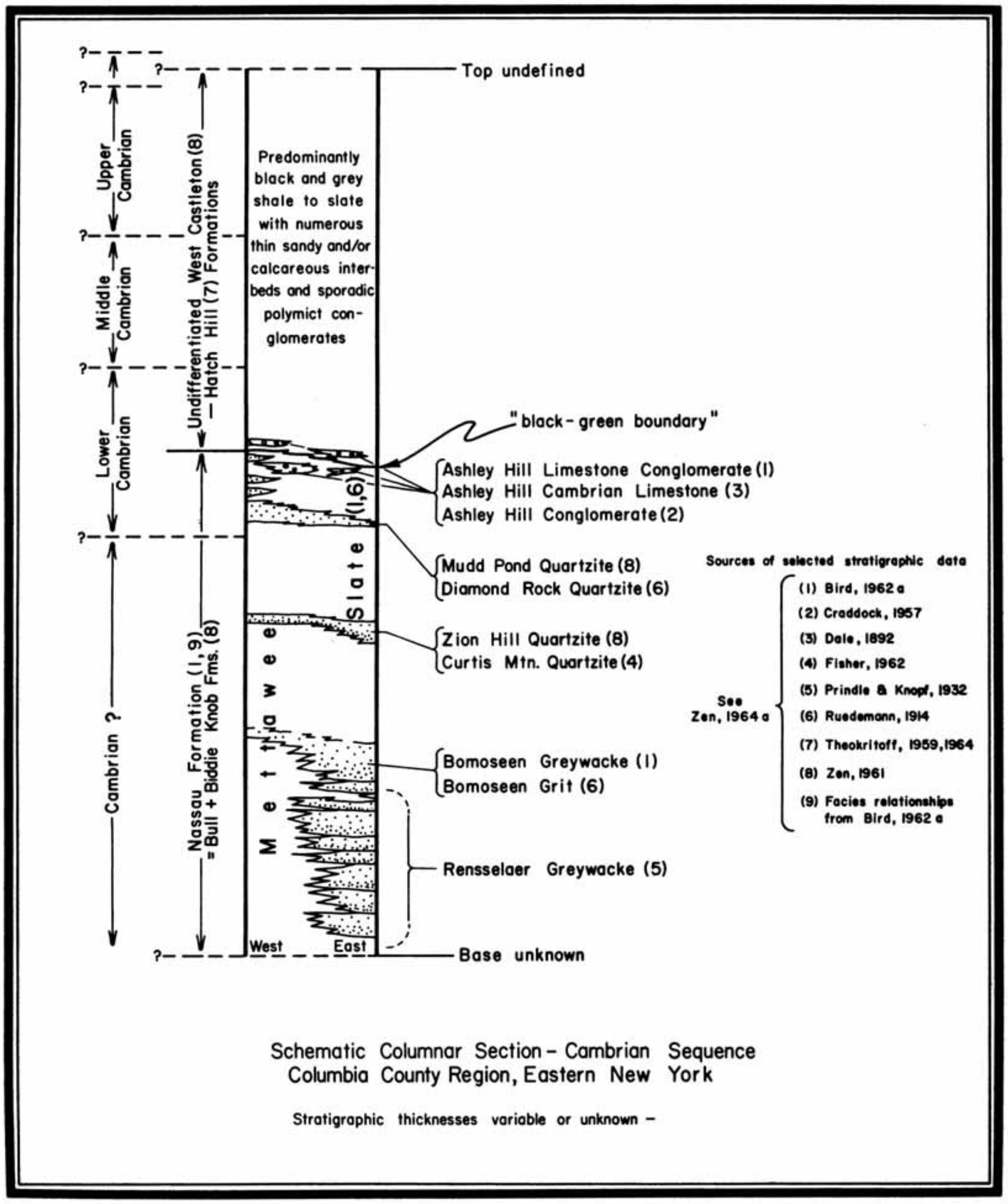


Figure 3 - Stratigraphy of Cambrian rocks in the Giddings Brook and Rensselaer slices of the Taconic allochthon, Columbia County, New York from Ratcliffe and others, 1975.

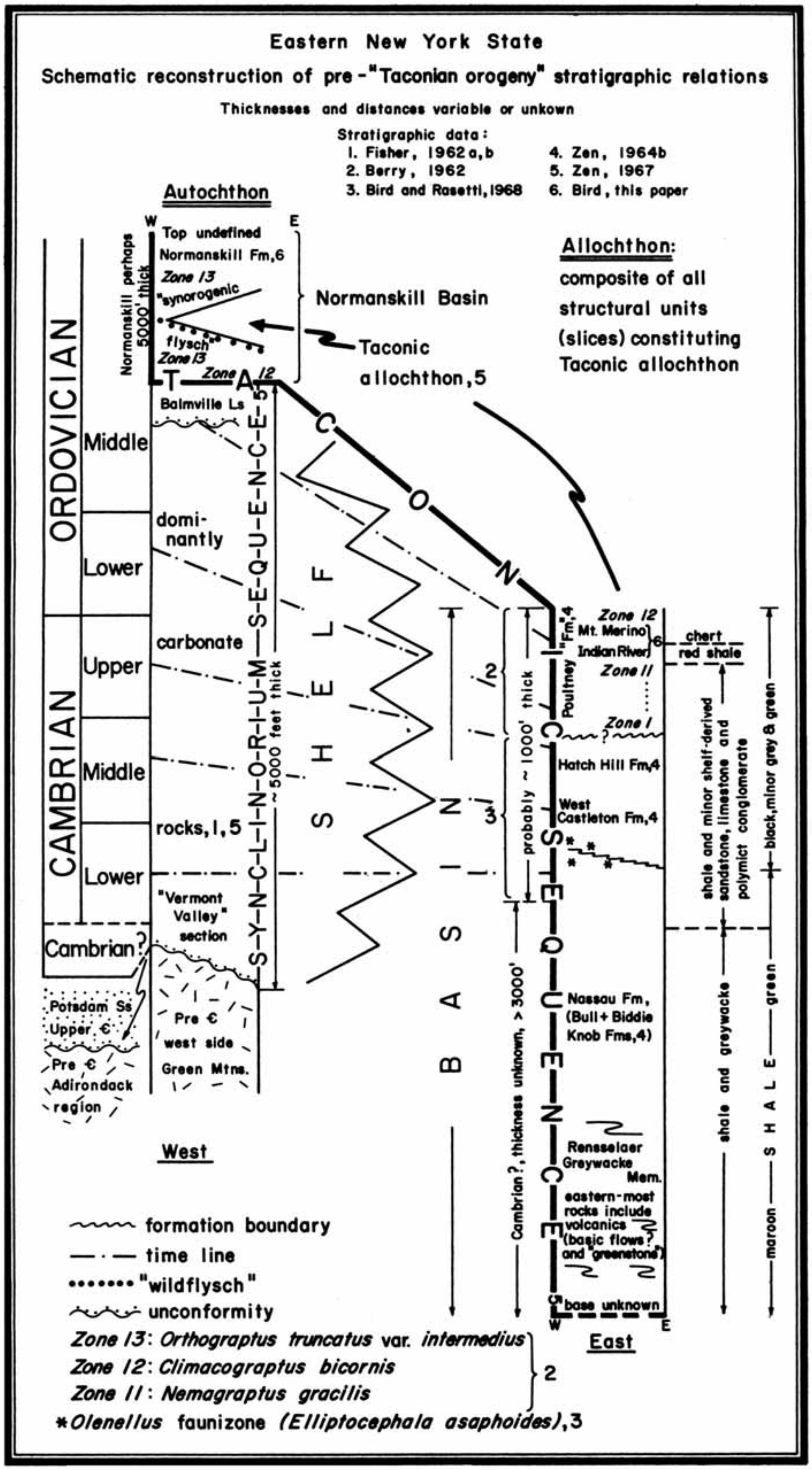


Figure 4 - Schematic reconstruction of pre-"Taconic orogeny" stratigraphy from Bird and Dewey, 1975.

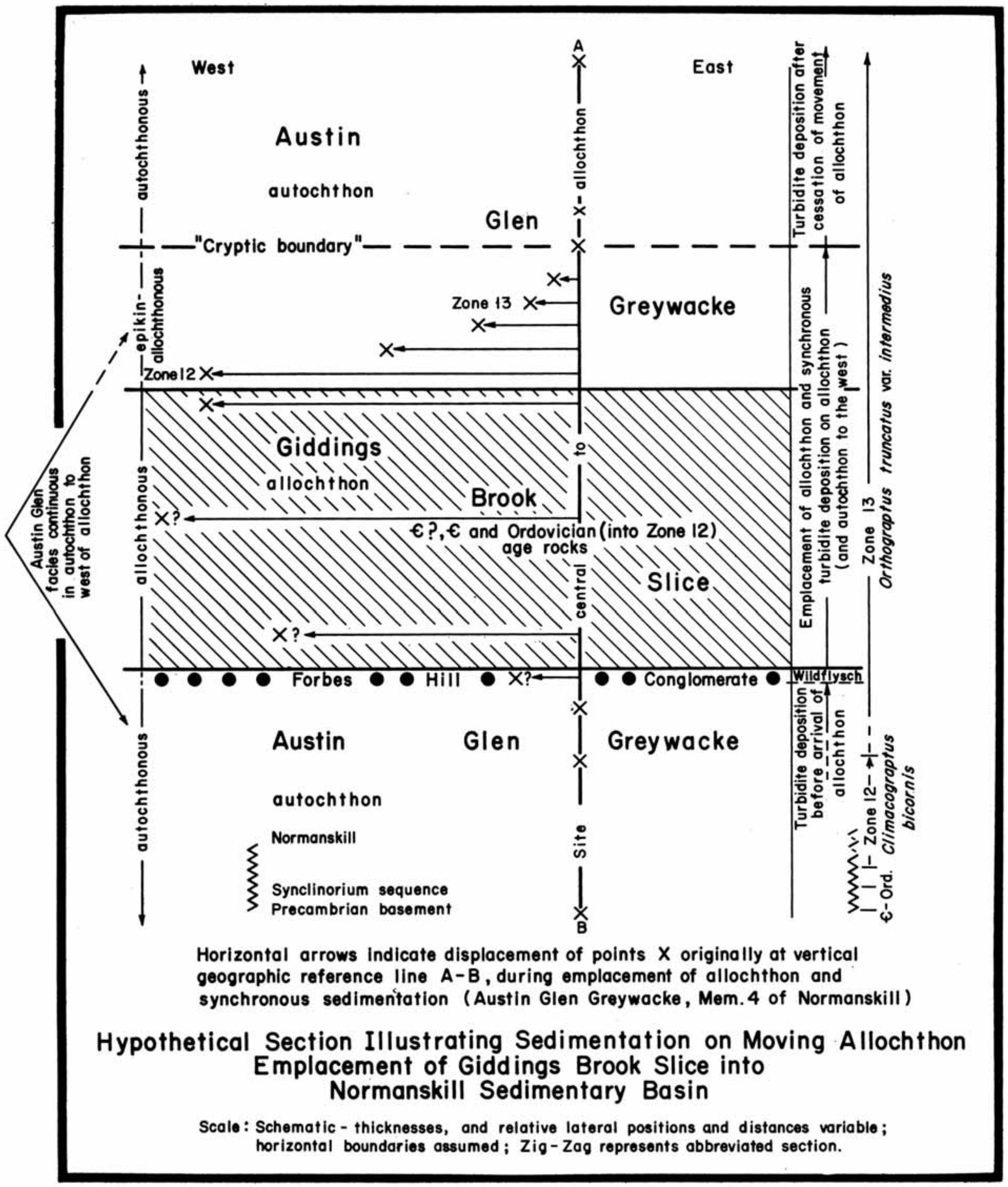


Figure 5 - Diagram illustrating paleontologic (graptolite) control on the emplacement of the Giddings Brook slice after Bird and Dewey, 1975.

Since the early apparent resolution of the Taconic problem by Ruedemann's critical fossil evidence, the structural history and provenance of the Taconic rocks have been greatly studied. The structural controversy revolves around the concept that the low Taconic slices were emplaced by gravity-induced sliding of the Taconic sedimentary strata along the sea floor to their final resting position atop the continental shelf. Thus, the Giddings Brook and Sunset Lake slices have, in the past, been interpreted as soft-sediment gravity slides driven by a slope reversal resulting from large vertical uplift in the vicinity of the continental slope and -rise (Figure 6). After the slope had reversed, the Taconic "rocks" slipped and slid into a subsiding basin to the west. Recent papers by Rowley and Kidd (1981) and Stanley and Ratcliffe (1985) have finally dispelled these picturesque notions of gravity-induced sliding, which were initiated by Cady (1945), and accepted by Zen (1961, 1967, 1972), Rodgers and Neal (1963), and others. Good old tectonics are now in vogue (as supported conceptually and in print by CM and JES), and the popular plate-tectonic version involves an arc-continent collision. This collisional model for the Taconic orogeny is discussed in detail below.

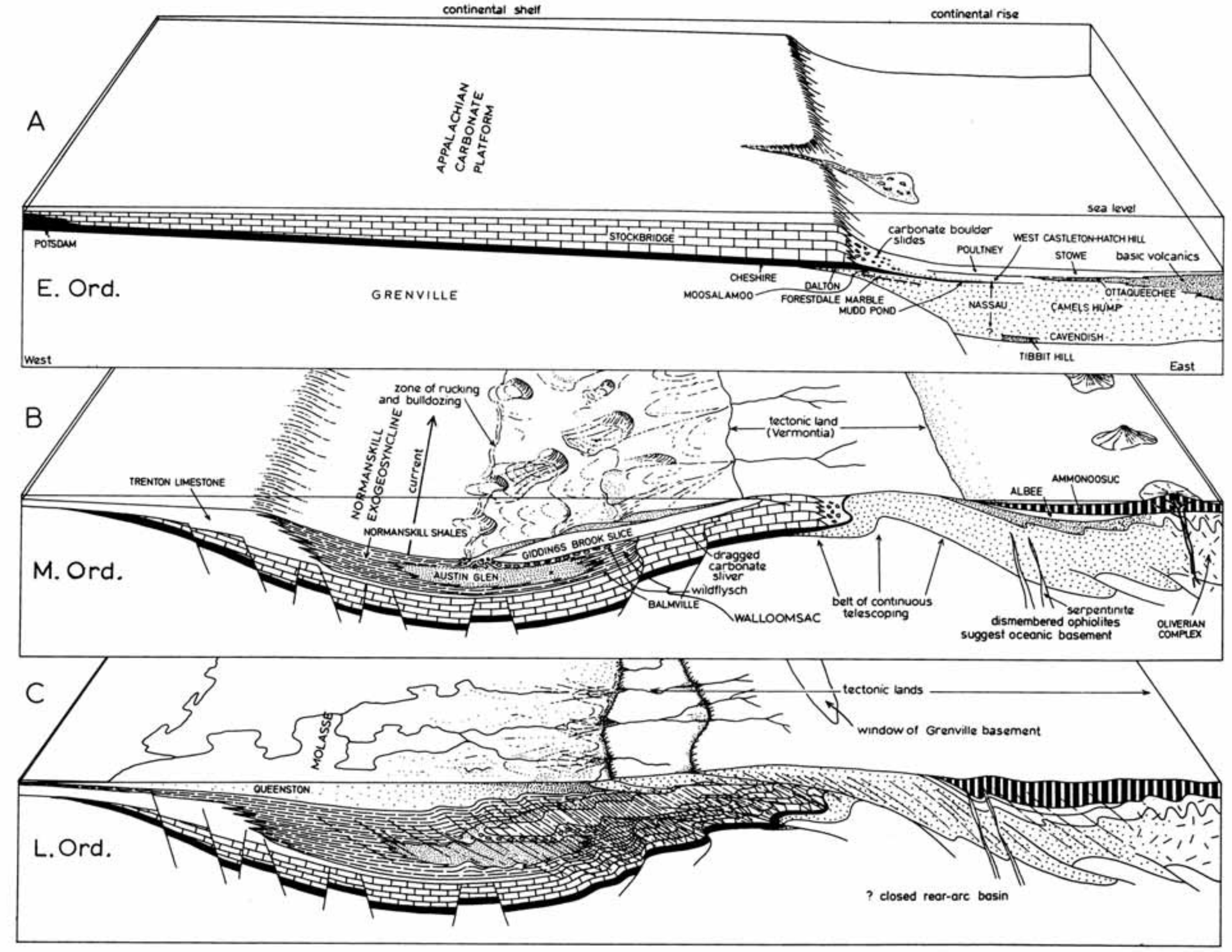


Figure 6 - Sequential block diagrams illustrating Ordovician tectonism and emplacement of Taconic slides as envisioned by Bird and Dewey, 1975.

THE BEDROCK UNITS OF THE FIELD-TRIP ROUTE

Layer I: Proterozoic Crystalline Basement Complex — Their True Story!

The oldest recognized strata in southeastern New York include the Fordham Gneiss in the Manhattan Prong physiographic province of the New York City area and the Hudson Highlands gneisses of the Reading Prong (Figure 7). In the Pound Ridge area (PR in Figure 7) the Proterozoic Y gneisses of the Fordham (a 1.1 Ga U/Pb age on zircons by Grauert and Hall, 1973) [Note: Ga (Giga) equals billion years ago] is cut by Proterozoic Z granitic gneiss (the Pound Ridge Gneiss and correlative Yonkers Gneiss [Y in Figure 7] farther south). The Pound Ridge gneiss is dated as latest Precambrian (579+21 Ma Rb-Sr age by Mose and Hayes, 1975) [Note: Ma (Mega) equals million years ago] and shows an intrusive, or possibly an unconformable relationship (Patrick Brock, personal communication) with the Grenvillian basement sequence. The Yonkers Granitic Gneiss has yielded ages of 563+30 Ma (Long, 1969) and 530+43 Ma (Mose, 1981). The Pound Ridge along with the Yonkers Gneiss, are thought to be the products of latest Precambrian alkali-calcic plutonism (Yonkers) and/or volcanism (Pound Ridge?) in response to rifting of the ancient Gondwanan supercontinent.

The rifting of the Proterozoic Y craton in latest Precambrian time thus sets the stage for the first of the trailing-edge continental margins of eastern North America. This trailing edge, (or passive margin I) was to receive clastic, then carbonate sediments of the Sauk Sequence of Layer IIA (see Tables 1 and 2). Recent work by Pamela Brock (1989) in the vicinity of the Peach Lake quadrangle, New York and Connecticut, shows the presence of a vast rift sequence (now metamorphosed) of potash feldspar-rich felsic gneiss, calc-silicate rock, volcaniclastic rock, amphibolite gneiss, and minor quartzite (Ned Mountain Formation) that rest unconformably on the Fordham basement rocks. As such, Pam Brock has identified an metamorphosed eastern dominantly volcaniclastic facies of the Proterozoic Z igneous activity marked by the Yonkers and Pound Ridge gneisses. In addition, this new and important work has illuminated and expanded the age, areal importance, and stratigraphic correlation of the Lowerre-Poughquag Cambrian(?) clastics at the base of Layer II.

On our field-trip route, north of the Manhattan Prong, we had hoped to examine the Hudson Highlands gneisses briefly at the Sloatsburg rest stop on the Thruway. But that place is being rebuilt and barriers have been built that preclude our getting a look at the rocks. Accordingly, take our word for it, they consist of a sequence of migmatitic, highly deformed, interlayered quartzofeldspathic- and pegmatitic granitoid gneiss, amphibolite gneiss, and calc-silicate rocks harboring dominantly flat-lying penetrative structural fabrics. A featured attraction is a mafic dike in which the dike rock displays a metamorphic foliation.

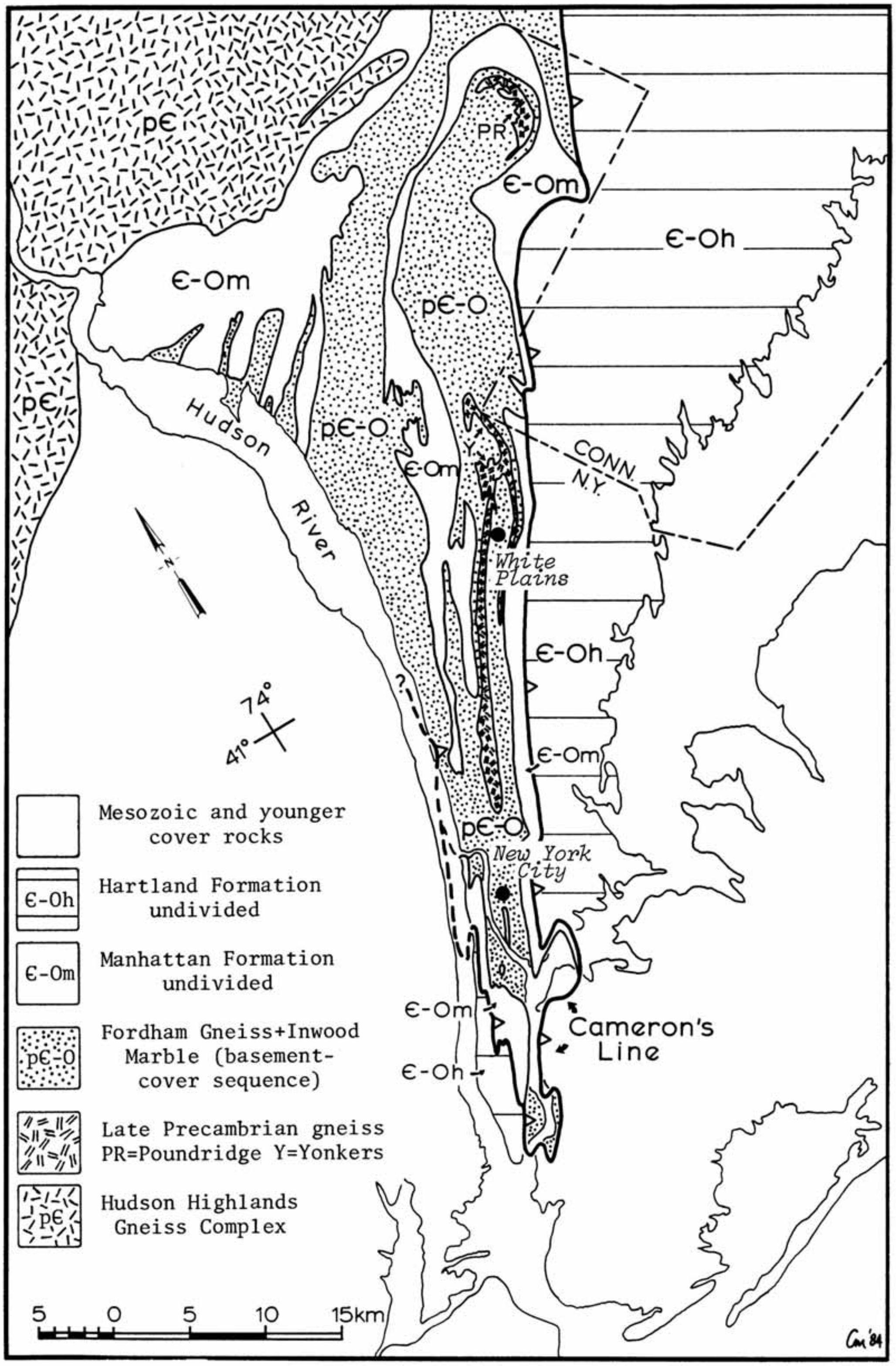


Figure 7 - Geologic sketchmap of the southern end of the Manhattan Prong showing the highly metamorphosed bedrock units. From Merguerian and Baskerville (1987).

Layer II : The Sequences in Lower Paleozoic Rocks

In this field-trip area are the depositional products of two contrasting paleogeographic-paleotectonic regimes:

(1) The regime of an ancient passive continental margin, which lasted from early in the Cambrian Period until the middle of the Ordovician Period (Figure 8) and which featured on the west a shallow, tropical carbonate shelf that passed eastward into deep water. On the shallow carbonate shelf, the Sauk Sequence [Layer IIA(W)] was deposited. East of the shelf edge, on a former continental rise, was deposited the Taconic Sequence of Layer IIA(E), a vast prism of fine-textured, predominantly terrigenous sediment. Still-farther eastward (oceanward) was a source of volcanic material.

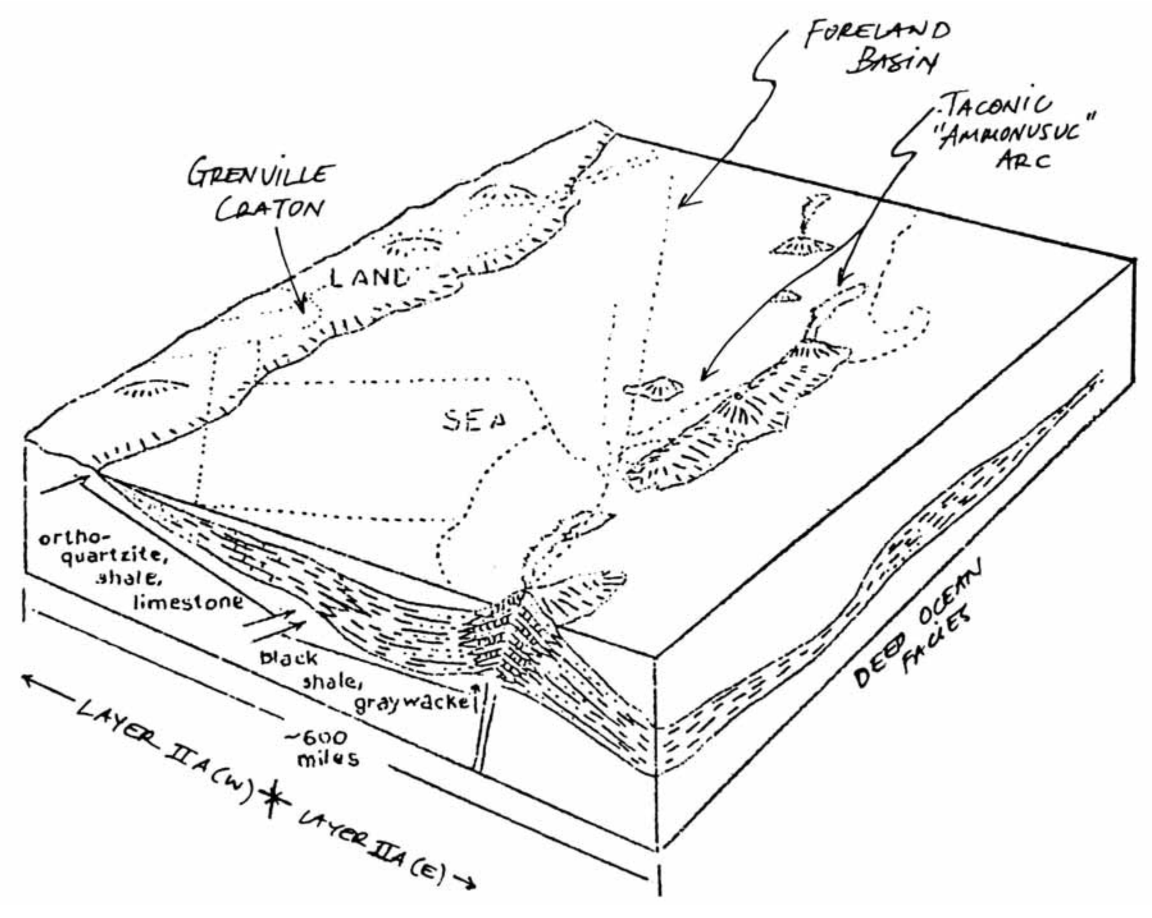


Figure 8 - Block diagram showing the Lower Paleozoic continental shelf edge of embryonic North America immediately before the deposition of Layer IIB. Current state outlines are dotted. The depositional areas for Layers IIA(W) and IIA(E), and the position of the Taconic arc and foreland basin are shown.

(2) The regime of an active convergent continental margin, which commenced later in the Ordovician Period and extended through at least the Silurian Period. The key depositional feature of this regime was a foreland basin, a vast synclinal trough that came into existence as a

consequence of the great loads imposed on the lithosphere by the overthrusts. This foreland basin subsided deeply. In its deep marine waters the shales and graywackes of the Tippecanoe Sequence [Layer IIB] were deposited above the Sauk Sequence dolomitic carbonates of Layer IIA. The evidence for this change consists of a karst landscape at the top of the carbonate succession and the covering of this karst surface with graptolite-bearing shales (Figure 9). The turbidites that we shall examine on this trip (Stop 9, in particular) were deposited in this foreland basin.

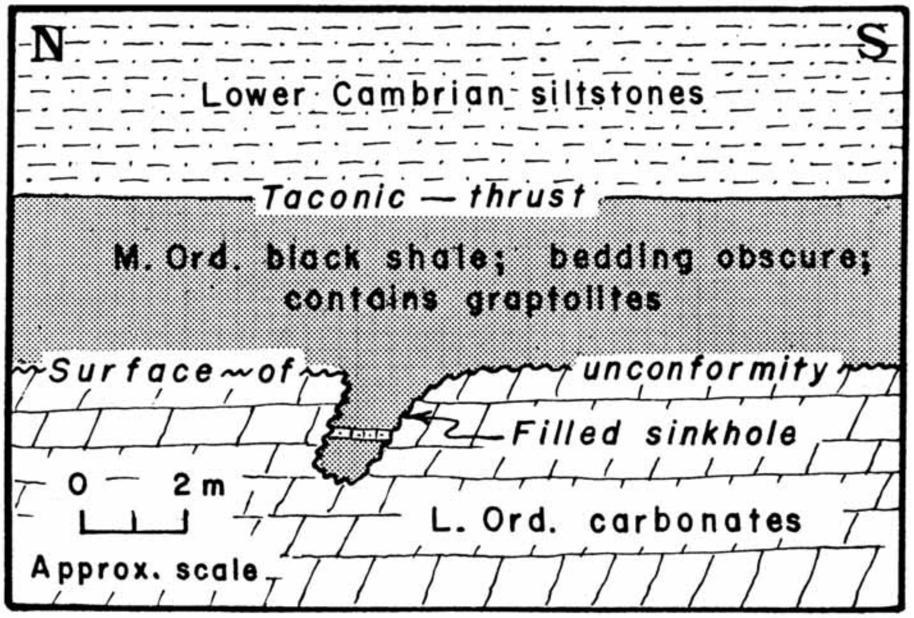


Figure 9 - West face of Bald Mountain, Washington County, New York, showing the three major units of the "Taconic Problem" in contact. The surface of unconformity proves that some terrigenous sediments do not have to be in thrust contact with the Cambro-Ordovician carbonate succession. The Taconic thrust of Cambrian siltstones against Middle Ordovician shales took place on the sea floor. Thus, locally, there is no major indication of thrusting (no mylonite, no contrast in minor structures above and below the thrust - thus nothing to show the presence of a thrust to investigators who do not pay attention to the fossils). Based on Sanders, Platt, and Powers (1961). Sketch by JES.

Sauk Sequence

In the area of our trip, which lies in the central part of the former carbonate shelf, the Sauk Sequence [Cambro-Ordovician carbonates of Layer IIA(W)] is known as the Wappinger Group (local name taken from Wappinger Creek, south of Poughkeepsie; note the spelling without a final "s" as contrasted with the spelling of the Town of Wappingers Falls, which features a final "s") or Kittatinny Group (New Jersey name), and their metamorphosed equivalents (Vermont Marble and Stockbridge Marble to the north and Inwood Marble in the New York City region). This vast sheet of Sauk Sequence carbonates is known elsewhere by other names. It is the famous oil-bearing Arbuckle Group of Oklahoma and Kansas; the Ellenburger Group of Texas; and the Knox Group of the southern Appalachians. In general, it consists of dolomite rocks of Cambrian and Early Ordovician ages. And, as noted, it is the protolith of the Inwood Marble.

The episode of accumulation of the Sauk Sequence ended when virtually the entire North American continent, formerly submerged by a shallow sea, became emergent and a surface of unconformity formed.

Tippecanoe Sequence

During the next episode of marine submergence, starting in the Middle Ordovician Epoch, the Tippecanoe Sequence began to accumulate. The initial deposits of the Tippecanoe Sequence consist predominantly of limestones (as contrasted with the generally dolomitic rocks of the underlying Sauk Sequence). These limestones are richly fossiliferous and have been studied extensively and subdivided to the maximum extent possible. A few local names applied to these limestones must be understood. In particular, the subdivisions of the Middle Ordovician limestones used early in the twentieth century were as follow:

Trenton

Middle Ordovician | Black River [Lowville Limestone in Upper Part]

Chazyan

These Middle Ordovician limestones are overlain by a thick body of terrigenous strata, shales at the base, coarse graywackes in the middle, and shales again at the top that are now considered to represent foreland-basin sediments which accumulated during and after the emplacement of the great overthrusts (to be discussed subsequently). Before the Sequence terms had been proposed and later applied in New York State, workers in the nineteenth century used the name "Hudson River shales" as a collective term for the shales and other terrigenous strata of the lower part of the Tippecanoe Sequence, the strata we shall study at Stops 5, 6, 8, 9, 10, and 11. The name "Hudson River" for the shales was continued well into this century (for example, in the geologic report on the Newburgh quadrangle, Holzwasser, 1926). Other names that have been applied to the thick terrigenous strata of the lower part of the Tippecanoe Sequence include Normanskill and Martinsburg. The Sequence names have arrived just in time. "Hudson River" is considered to be old fashioned and Normanskill and Martinsburg have been given specific time connotations. What is more, the correct age assignment of the distinctive Normanskill graptolite faunas is not a matter of agreement among the experts, as we explain in the section dealing with the Taconic "problem."

A second complication with the terrigenous strata of the Tippecanoe Sequence is their thickness, a difficult problem compounded by lack of large, continuous exposures; lack of a detailed stratigraphic subdivision; and by complex effects of multiple episodes of tectonic deformation.

From time to time, contrasting thickness values have appeared in the literature based on: (1) guesses by those who did not attempt to work out the stratigraphic succession nor geologic structure but whose "sixth geologic sense of how things ought to be" informed them that the number should be small (i.e., no more than a few hundred meters); (2) calculations made after careful mapping; and (3) the results of exploratory borings.

Ruedemann pioneered the category (1) "thick-small" version of the thickness of these shales. Ruedemann based his conclusions on his mapping of the region around Saratoga Springs and study of a well at Mechanicville that cut 1400 feet of shale where the dip was about 70° and the beds were repeated on overturned folds. He concluded (in Cushing and Ruedemann, 1914, p. 91) that: "the thickness of the shale in the well is clearly no indication of a corresponding thickness of shale beds." Ruedemann arrived at his preferred estimate of 1000 feet from studying expsoed strata on the west face of Willard Mountain.

Table 3 shows various subdivisions of the Martinsburg Formation made by geologists who studied this formation in eastern Pennsylvania and adjacent New Jersey. Two examples of category (2) results are those by Behre (1927, 1933) from the slate belt of eastern Pennsylvania and by Drake and Epstein (1967) based on detailed mapping in New Jersey.

Exploratory borings in the Hudson Valley have supported these large thickness determinations. At least three exploratory borings have been drilled in locations where the hole penetrated 8000 feet or more of shale, probably much more than the operators had imagined would be present. The Senigon boring, Quebec, cut 4000 feet of shale. The Columbia Gas No. 1 D. J. Finnegan boring in southern Washington Co., NY, penetrated 2760 feet of Taconic strata and 2000 feet of mid-Ordovician (presumably Utica) shale. The Crom-Wells No. 1 Fee, SW of Middletown, Orange Co., NY drilled through 4700 feet of shale.

Taconic Sequence

The Taconic sequence refers to the predominantly fine-textured terrigenous strata (Layer IIA(E)) that were deposited seaward of, and in much deeper water than were the Sauk Sequence (Cambro-Ordovician) dolomitic carbonates and continued to be deposited during the time when the Knox unconformity was forming and while the lower parts of the Tippecanoe Sequence were accumulating.

The Taconic "Problem"--a Historical (and, at Times, Hysterical) Perspective

Early in the history of geologic studies, during the First Geological Survey of the State of New York, in the 1830s and 1840s, a sure way to guarantee one's entry into "geologic heaven" was to propose a new geologic system. Proposals for two new systems were made by New York's first geologists. Ebenezer Emmons proposed the "Taconic" system, and James Hall, the "New York" system.

Emmons studied the thick, fine-textured, predominantly terrigenous strata (siltstones and slates) that are now known to be of Cambro-Ordovician age and to belong to the Taconic Sequence [the deep-water equivalents of the Sauk Sequence (Cambro-Ordovician shallow-water dolomitic carbonates) and lower part of the Tippecanoe Sequence (with basal limestones spanning the Chazyan to early Trentonian part of the Middle Ordovician and the overlying mid-Trentonian and younger foreland-basin shales and graywackes)]. Hall's New York system includes strata that proved to be correlative with Sedgwick and Murchison's (1838) Devonian system. Before this was known, and in order to increase the chances for adoption of his own proposed new system, Hall did his best to scuttle Emmons' Taconic system. Hall "sandbagged"

Emmons at every turn, including making an incorrect identification of a key fossil found by Emmons (the only known example of such an error by New York's eminent State Paleontologist).

The "Hudson River shales" were not part of Emmons' Taconic system, but became part of the "Taconic problem" when the field geologists (for example Arthur Keith, 1932, and E. B. Knopf, l927) began to recognize only two major units: (1) the Cambro-Ordovician carbonates, (considered as a single unit, but as we have seen, now assigned to the Sauk Sequence and basal limestones of the Tippecanoe Sequence) and, (2) the fine-textured terrigenous strata (depending on age and characteristics now referred either to the lower part of the Tippecanoe Sequence or to the Taconic Sequence). Because all the fine-textured terrigenous strata, including the "Hudson River shales" that had been assigned to the Taconic strata, were shown by fossils to be the same ages as the carbonates (both spanned a range from Early Cambrian to Medial Ordovician), and occupied a structural position above the carbonates, the concept was proposed that a large Taconic overthrust had displaced the Taconic strata westward on the order of 100 km or more. (See summary in Kay, 1937.) The displaced Taconic strata were thus considered to constitute a vast allochthon.

Second, the Normanskill Formation. The age of the Normanskill Formation lies at the heart of the Taconic problem; indeed, the controversy over the correct age of the Normanskill delayed any rational solution to the Taconic problem for more than fifty years. The key players in the early scenes of the drama were Rudolf Ruedemann and E. O. Ulrich; more recently, W. N. B. Berry, Jean Riva, D. W. Fisher, and L. V. Rickard have joined in.

When Ruedemann (1901a) first described the Normanskill fauna, he suggested that its age was Late Trentonian (in the older sense; not Late Trentonian of G. A. Cooper, 1956). Ruedemann's reasoning was based on his finding of fossiliferous limestone pebbles in a formation that he had named the Rysedorph Hill Conglomerate. Some of these pebbles contained Early Trentonian fossils. Because the Rysedorph Hill Conglomerate is intercalated within the Normanskill Formation, Ruedemann (1901b) correctly concluded that the age of the Normanskill must be post-Early Trentonian (refer back to the table of the subdivisions of the Middle Ordovician basal Tippecanoe limestones). The key graptolites in the Normanskill fauna were associated with the genus Nemagraptus. On the face of it, one would think that this would settle all questions of stratigraphic age. In modern terms, we would say that Ruedemann had demonstrated that the Normanskill belonged in the lower part of the Tippecanoe Sequence.

However, before the concept of Sequences was introduced, things were not that simple. And why? Because one of Ruedemann's contempraries was a crusty character named E. O. Ulrich. Mr. Ulrich was a powerful individual and he thought that he understood the stratigraphic relationships of the Ordovician strata in northeast Tennessee beyond any shadow of doubt. The key correlation that was not challenged involved the diagnostic Nemagraptus fauna, found in both the Normanskill of New York and the Athens Shale of Tennessee. In short, wherever one of those formations fit into the time-stratigraphic scheme, the other would have to go with it.

Ulrich asserted positively that his age assignments for the Ordovician rocks of northeast Tennessee had been clearly established beyond any doubt. There, the Athens Shale underlies a distinctive fine-textured limestone that looks just like the Lowville Limestone of New York. Indeed, it had been given the name Lowville, and most workers were happy both with this name and the accompanying interpretation, namely, that the formation was the same age as the New York Lowville (which belongs to the Black River subdivision). Therefore, whatever underlay the Lowville had to belong to an older subdivision, that is would be of Chazyan age. Accordingly, Ulrich was convinced that the correct age of the Nemagraptus fauna of the Athens Shale of Tennessee (and also the Normanskill of New York) was Chazyan. In the face of Ruedemann's new data about the Late Trentonian age of the Nemagraptus fauna, one might have supposed that Ulrich would have reevaluated his faith in the Lowville Limestone situation. (As it later worked out, B. N. Cooper and G. A. Cooper in 1946 showed that the limestone in Tennessee is much younger than Ulrich thought, i.e., it is a correlative of the New York Trenton, not the New York Lowville.) But, Ulrich was Ulrich and he thought the Lowville was the Lowville. Accordingly, Ulrich thundered down on poor Ruedemann. Ulrich's message: THE NORMANSKILL IS CHAZYAN--period, exclamation point!

In the face of Ulrich's dogmatic insistence, Ruedemann actually abandoned his original correct assignment of the age of the Normanskill as Late Trentonian. Everytime Ruedemann wrote about this, he would quote Mr. Ulrich as "authority" for a Chazyan assignment. As a result, much of Ruedemann's geologic mapping turned out to have been wrong. Everywhere he showed the supposedly Chazyan-age Normanskill to be in contact above with the subjacent limestones of the basal part of the Tippecanoe Sequence (whose topmost unit was the Lower Trenton Limestone), he had to map an overthrust between them (Chazyan above Trentonian).

One can only wonder at what private thoughts must have been dancing around inside Rudolf Ruedemann's head each time he was forced to "knuckle under" in print to Ulrich by reciting that Mr. Ulrich said the age of the Normanskill is Chazyan. Perhaps Ruedemann soothed his conscience by including his persistent disclaimers that the Normanskill might be as young as "Black River." (Ruedemann was thus trying to bring the Normanskill up in the column where he thought it belonged, but did not want to get Mr. Ulrich's back up by going as high as Trenton.)

How much farther along New York stratigraphy and structure would have been if Ruedemann had been a more-combative individual. Scientific progress would have been greatly served had Ruedemann stood up on his hind legs on the age of the Normanskill and told E. O. Ulrich to go right straight to hell on this matter (and could have made that remark stick). As it was, Ruedemann lacked the courage of his correct scientific conviction, and the whole subject was a mess until W. B. N. Berry straightened it out in the 1960's. At last, the Taconic "problem" seemed to have been solved (Zen, 1961, 1963, 1967; Sanders, Platt, and Powers, 1961; Platt 1962; Theokritoff, 1964).

But wait! Not so fast! That ship does not sail until Friday! Lo and behold, in 1973 Rickard and Fisher accepted J. Riva's recent contention that the age of the Normanskill is Chazyan! Thus, they have led everyone willing to follow right back to E. O. Ulrich's age assignment. A proposal, carrying the weight of the authority of the New York State Paleontologist (Rickard, the incumbent, and Fisher, recently retired and now Emeritus) and thus having "official" sanction is not to be taken lightly by those who rely on such "official" pronouncements for their correlations. In JES' opinion, this "born-again" Chazyan age assignment of the Normanskill is totally without merit. The result of its publication and adoption on the 1972 version of the Geologic Map of New York State, has been a reassignment of the strata in all localities previously mapped as Normanskill to the Taconic Sequence, the only reason being this new "official" Chazyan age.

As long as the terrigenous Normanskill strata are classified as being of Chazyan age, then they must belong to the Taconic Sequence and therefore are a part of the Taconic allochthon (i. e., terrigenous strata same age as and above the carbonates). By contrast, if the age of the Normanskill initially assigned by Ruedemann and supported by W. B. N. Berry (1960, 1962, 1963) (i.e., post-Lower Trenton) is considered to be correct, then Normanskill above carbonates definitely does not involve the Taconic Sequence or the Taconic allochthon. To the contrary, Trenton-age Normanskill terrigenous strata belong in the Tippecanoe Sequence, and unconformably overlie the basal limestones of the Tippecanoe Sequence. The contact is a result of subaerial exposure of the carbonates and subsequent formation and subsidence of a foreland basin along the eastern edge of the former shallow-water carbonate shelf (Figure 9).

The Taconic Orogeny

The overthrusts with which the origin of the foreland basin have been associated were the initial products of a mountain-building event known as the Taconic orogeny. As a result of this orogeny, mountains were elevated where formerly the sea stood. From these mountains, coarse sediments were shed westward toward the interior of the continent.

The first major overthrust event involved duplication of the Sauk Sequence and lower parts of the overlying Tippecanoe Sequence along the Champlain and related thrusts. In northwestern Vermont, the Champlain thrust is overlain by Lower Cambrian quartzites; no underlying Precambrian basement rocks are involved. Farther south, from Stissing Mountain, Dutchess County, New York, and into northwestern New Jersey, the Lower Cambrian quartzite rests nonconformably on Precambrian, usually graphitic, rocks that locally at least can be shown to be overthrust against the lower part of the Tippecanoe Sequence. Somewhat later, the Taconic allochthon was emplaced. Within this allochthon, the fine-textured terrigenous sediments of the Taconic Sequence [Layer IIA(E)], the former ancient continental- rise deposits, were displaced westward to positions above the Sauk Sequence carbonates [Layer IIA(W)] and the strata of the lower part of the Tippecanoe Sequence [Layer IIB]. A complicating factor is that the great overthrusts, both those of the Champlain family involving the Sauk Sequence +/- the underlying felsic (and graphitic) continental-type basement rocks and the Taconic allochthon (which involves only strata and never any basement of any kind) moved along the sea floor of the foreland basin.

The late Middle Ordovician orogenic events are collectively designated as the Taconic Orogeny. Formed during this orogenic episode were the Champlain family of overthrusts (as noted, from Stissing Mountain southwestward, involving continental-type Precambrian basement) as well as the Sauk Sequence and part of the Tippecanoe Sequence and Taconic overthrusts (and, as already mentioned, involving only the Taconic Sequence and never any pre-Taconic basement). At the same time, and somewhat earlier, an extensive fold belt, a zone of regional metamorphism, and various plutons dated at roughly 460-400 Ma. were intruded (see Table 1). As mentioned, while the deep-water turbidites and related sediments of the Tippecanoe Sequence were accumulating in the foreland basin, the great overthrusts moved along the former sea floor. To many geologists, subscribing to the older thinking (Zen, 1967; Bird and Dewey, 1975; Ratcliffe and others, 1975) (See Figure 6.), the Taconic orogeny was envisioned as a series of gravity-induced slides (the Low Taconics) and eventually overthrusts (the High Taconics) of the oceanic sequence [Layer IIA(E)] above the Sauk Sequence carbonate-shelf deposits [Layer IIA(W)] and overlying flysch of the Tippecanoe Sequence [Layer IIB]. This episode of continentward displacement was driven by the encroachment of a volcanic arc (the Ammonoosuc-Oliverian Complex in Figure 6) against the passive continental margin of Ordovician North America.

Many modern workers [including CM, JES, Rowley and Kidd (1981), Stanley and Ratcliffe (1985)] do not believe in gravity sliding as a model for the emplacement of the structurally lowest Taconic allochthons. Rather, based on stratigraphic- and structural evidence, these workers envision all Taconic displacements resulted from continentward overthrusting of a subduction (JES would insist, obduction) complex formed between the oceanward-facing continental-margin sequence and the encroaching Taconic arc (Figure 10). The main argument for gravity-induced sliding of allochthons, the presence of olistostromes and wildflysch conglomerates on the western, leading edge of the Taconic allochthon (See Figure 1.), are now interpreted as deposits of forethrust olistostromes in front of an overriding accretionary wedge. As far as is now known, the Taconic allochthon itself includes only sedimentary strata; no pre-Taconic continental basement has been found. However, such massive overthrusts of strata over strata undoubtedly are accompanied by thrust slices in which the basement overrides sedimentary strata. In eastern New York State, slivers of Cambro-Ordovician carbonate have been mapped and identified within the base of Taconic sole thrusts by Zen and Ratcliffe (1966) and by Ratcliffe and others (1975). [JES thinks this sliver stuff is hot air blown out in ignorance of the pre-Taconic Champlain family of overthrusts that involve the Precambrian, Sauk Sequence, and Tippecanoe Sequence, and of the importance of high-angle normal faults of probably mid-Jurassic ages.]

In Newfoundland, thick slices of oceanic lithosphere (i.e., an ophiolite succession) have been thrust over the Cambro-Ordovician shallow-water carbonate-shelf deposits (of Sauk and basal Tippecanoe Sequences). Detrital chromite, a mantle-derived chromium oxide, probably shed westward during subaerial exposure of ophiolitic slabs, has been found in the flysch deposits associated with the Newfoundland "Taconics".

An important point associated with the concept of the Champlain family of overthrusts where they involved the Precambrian basement is that post-thrust uplift and erosion probably removed large amounts of such slice(s) of granitic basement and that the only parts remaining are those that have been protected from erosion by being downdropped. This possibility is mentioned here because erosion of an overthrust block composed of granitic basement rocks could have provided a supply of coarse quartz to form the Lower Silurian Green Pond-Shawangunk-Tuscarora-Clinch sheet of sandstones and local conglomerates at the base of Layer III. Alternatively, the thick quartzose deposits could have been formed from reworked bull quartz veins found along the Taconic thrust faults (JES thinks this is a lot of bull, quartz!), or from eroded pegmatites associated with the roots of the Taconic volcanic arc. The parent deposit of all this Silurian-age quartz is, as yet, a mystery.

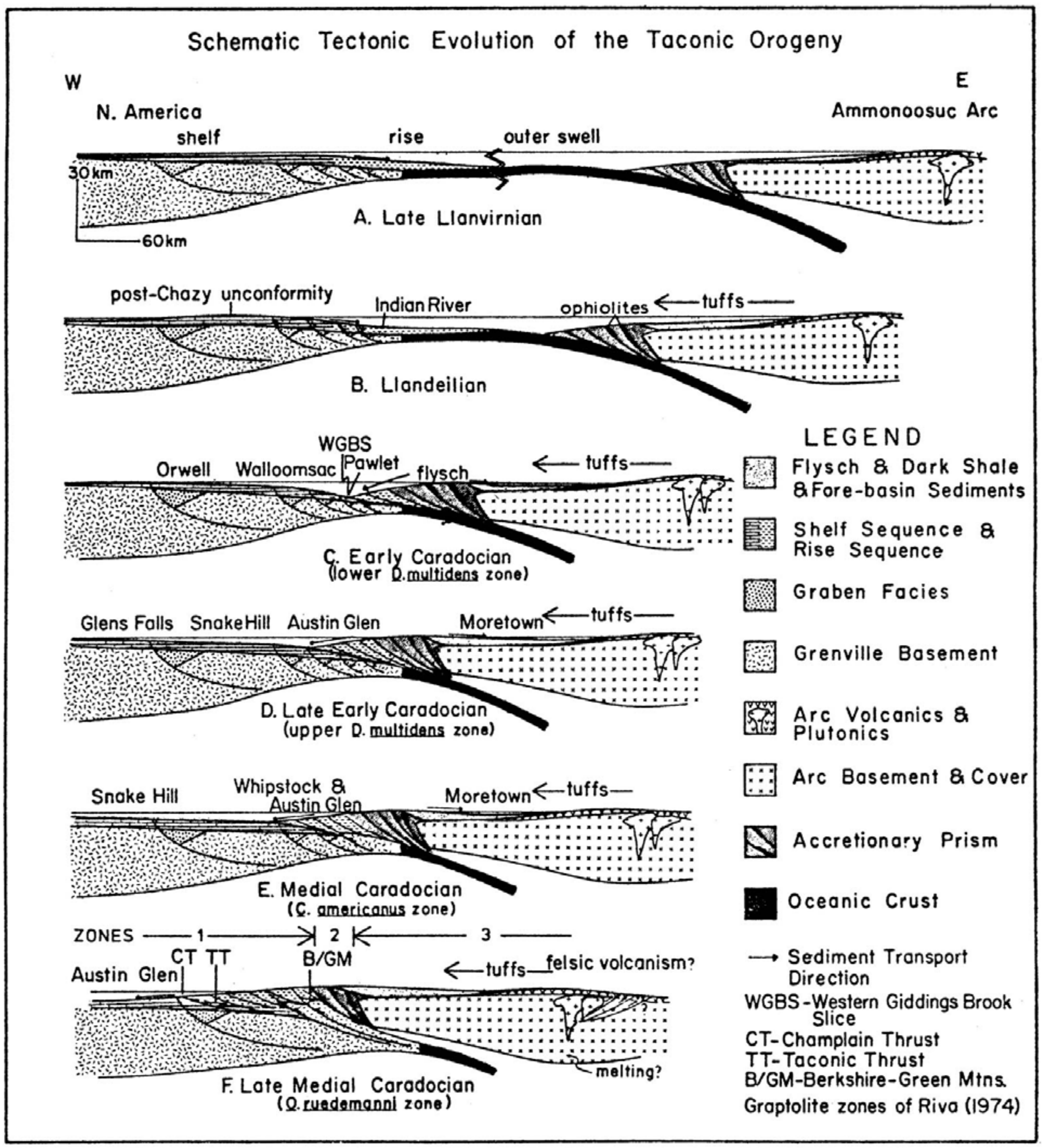


Figure 10 - Sequential tectonic cross-sections for the Taconic orogeny in New England. From Rowley and Kidd (1981).

Similar to the relationships noted in the Antler orogenic belt of California and Nevada, the deep-seated Taconian folding, metamorphism, and igneous activity occurred shortly before the Taconic allochthon had been emplaced (Merguerian, 1985). Available age data indicate that the compressive ductile deformation in the igneous- and metamorphic root zone of the Taconic orogen led the supracrustal emplacement of overthrust sheets by a minimum of 20 Ma. The polydeformed internal massifs presumably mark the deep levels of continentward-facing accretionary complexes within which deep subduction and deformation of oceanic deposits preceded the collision of the encroaching volcanic-arc terranes. Final docking of the arc resulted in cratonward thrusting of the shallow levels of the subduction complex to form the Taconic allochthon. As such, we see a time gap in deep-seated versus supracrustal deformation, wherein a geometrically predictable vertical pattern of diachroneity within subduction complexes in collisional orogens occurs.

Post-Taconic Crustal Disturbances

Following the Taconic orogeny, the rocks of southeastern New York were effected by a number of Paleozoic mountain building disturbances which involve folding, metamorphism, and faulting (both high- and low-angle). As summarized on Tables 1 and 2, the Acadian orogeny of Devonian age included folding, metamorphism, and intrusion of granite (the Peekskill granite and others). In addition, the Acadian orogeny produced high-angle reverse faulting and possibly low-angle thrusting of the rocks of Layer III. After the Acadian orogeny, southeastern New York underwent an episode of continued uplift and erosion. By the Permian Period, the terminal phase of the Appalachian orogeny took place. This phase, sometimes called the Alleghanian orogeny, is best observed in the southern Appalachians and in Rhode Island where rocks of late Paleozoic vintage are directly affected by folding, faulting, intrusion, and metamorphism. In these widely separated areas, low-angle overthrusts involving basement, and coincident folding of sedimentary cover rocks have been well documented. In addition, the coal in Pennsylvanian strata of Rhode Island was metamorposed to graphite grade and in eastern Connecticut, granites were intruded.

Armchair geologists (or plate pushers) conjecture that the Acadian orogeny was driven by continentward subduction of ocean crust to the oceanward side of the Taconian arc-continent collision zone. Thus the Acadian orogeny, basically a brief, thermal event, could be visualized as the result of Andean-type subduction. Following a period of strike-slip displacement of geologic terranes, the "big one", as Fred Sanford would say, occurred. The Alleghanian orogeny is thought to be the result of a continent-continent collision between North America and Africa to close out the Paleozoic Era. Studies of deep seismic- reflection profiles across the southern Appalachians have demonstrated the significance of low-angle overthrusts of crystalline basement rock. In some cases, layered reflectors (probably Paleozoic sedimentary strata) are trapped beneath the huge overthrust sheets. Clearly, the effects of late Paleozoic low-angle thrusting cannot be discounted in southeastern New York just because the post-Devonian strata were here eroded (or not deposited).

From this brief summary it should be clear that many post-Taconic events can be called upon to explain the multitude of folds and low- to high-angle faults in Taconic rocks throughout southeastern New York. In addition to these episodes of deformation of Paleozoic age, remember (Table 1) that during the Triassic and Jurassic Periods, the rocks in eastern North America experienced several episodes of large-scale normal- and strike-slip faulting (Palisades "disturbance"). Soon afterward, North America and Africa split apart again. Commonly, the rejuvenation of plate motions reactivates pre-existing weak zones in the Earth's crust. Thus, it is not uncommon to find that the movement histories of faults are complex and may, in fact, record protracted Taconic-, Acadian-, Appalachian-, as well as Palisadian tectonic activity. (See Tables 1, 2.) In the field, we shall attempt to identify and discuss these post-Taconic structures and develop the idea that high-angle faulting and block uplifts (horsts) and downwarps (grabens) can cause abrupt changes in lithology and metamorphic grade. Steep metamorphic gradients, truncated low-angle thrust faults, and rapid lithologic variations may be the result of such faulting.

Because of the likelihood that large-scale overthrusts took place in the Hudson Valley region during the Late Paleozoic deformation, it needs to be emphasized that an authochthonous structural position with respect to the Late Ordovician deformation does not preclude an allochthonous position during the Late Paleozoic deformation.

Layer III - The Siluro-Devonian Carbonate- and Terrigenous Strata

In the aftermath of the Taconic orogenic event which involved an arc-continent collision resulting in continent-scale overthrusting of deep-water eastern Taconic strata over shallow-water western carbonates, folding, local metamorphism, and mafic (alkalic) intrusive igneous activity, uplift and erosion created a planation surface atop which Silurian and Devonian strata were eventually deposited. This surface of unconformity, which crops out in a number of places will be visited on Day Two (Stop 12), and is marked by underlying deformed Taconic slates and overlying, subhorizontal Silurian and younger carbonate and clastic rocks.

The Silurian and Devonian strata of eastern New York State mark an important succession of basal terrigenous clastics (including the Shawangunk Formation, High Falls Shale, and Binnewater Sandstone), overlain by waterlimes of the Manlius and Rondout Formations which grade upward into a magnificent collection of carbonates of the Helderberg Group of Devonian age. The carbonates, together, form an impressive carbonate bank analagous to the present-day Bahama Banks off of the southeastern United States.

Gradually, the carbonate succession was replaced by conglomerate, chert, siltstone, shale, and eventually coarse clastics that grade upward into the famous Catskill redbeds or "Old Red Sandstone". Thus, the Catskill fan-delta complex was built upon the carbonate bank as uplift and erosion of the Acadian orogenic belt (in New England) shed coarse clastics continentward and eventually, but not without occasional marine incursions, built up an intracontinental delta. So the next time your friends invite you to go to "the Catskill Mountains" be sure to correct your friends, resolutely, by informing them that "they're not mountains, they are a dissected, uplifted fan-delta complex!" At any rate, Table 4 lists the Silurian and Devonian formations of Layer III and their thicknesses in the southern part of our field trip route for your reference. We will not be examining these units on the Taconic trip directly (except for Stops 11 and 12) but will "view them from afar" as we drive.

GLACIAL DEPOSITS

Glacial deposits include several contrasting varieties including till and outwash. Till is a general name for any sediment deposited directly by the flowing ice of the glacier. Typically, till is not stratified and contains a wide range of particle sizes, from boulders to clay, Outwash is a general term for any sediment deposited by water melting from a glacier. Outwash includes such contrasting sediments as stream sands and lake clays. The key point about recognizing outwash is the stratification that resulted from the action of water.

An important point to be determined in studying a glacial deposit is which way the glacier flowed. Because glaiers create scratches and even larger grooves on solid bedrock, it is usually a straightforward matter to infer ice-flow direction. It is along the trend of the linear grooves, striae, and other elongate features. Direction of flow may also be inferred by studying provenance; that is, the source of the particles in the deposits. Because glaciers can transport stones long distances, one commonly finds a collection of glacial particles unlike the bedrock on which the glacial deposits rest. Such stones are known as erratics. If an erratic can be traced to a distinctive source, it becomes an indicator stone. The use of striae and indicator stones shows that glaciers flowed across the New York region from several directions.

Figure 11 shows a map of North America with what was for a long time the standard view of how the Pleistocene ice covered Canada and northern United States. Notice that southeastern New York is within the flow pattern shown for the Labrador Ice Sheet. Given the concept that ice from the Labrador center should have been present in New York City, then the expected direction of such glacier flow is from the NNE to the SSW, a direction that is parallel to the Hudson River. However, in Manhattan and on the top of the Palisades Ridge, striae are oriented from about N20°W to S20°E, or even more toward the NW-SE direction. A previous generation of glacial geologists adopted the view of deviated flow from a central lobate glacier (Figure 12). According to this concept, the main flow of the latest (and, according to many, the only Wisconsinan) glacier was concentrated down the Hackensack lowland, but the ice deviated to its left and crossed the Palisades ridge and New York City on a NW to SE course.

From studying the stratigraphic relationships, provenance, and grooves on the bedrock, JES and CM propose an alternative view (Sanders and Merguerian, 1991a, 1992a). In our scheme of things, the flow indicated in Figure 12 is not the product of one glacier, but of more than one (two, possibly more). Figures 13 and 14 show how we interpret the glaciers in the same area of Figure 12. In Figure 13, the ice flowed rectilinearly from NW to SE, across the highest ridges and across the Hudson Valley without deflection. This suggests a thick ice sheet whose flow pattern was governed by the gradient on the top of the glacier. Figure 14 shows the flow from NNE to SSE as resulting from a later glacier. According to our new models, the two prominent moraine ridges on Long Island resulted from ice flowing as in Figure 13. The latest glacier, shown in Figure 14, did not reach much of Long Island. It covered parts of Queens and Brooklyn, Manhattan, and Staten Island. The distribution of erratics derived from as far away as the anthracite district in eastern Pennsylvania (Figure 15) in the redbrown tills and outwashes in New York City lends strong support to JES' interpretation shown in Figure 13, as contrasted to Figure 12.

Figure 11 - Reconstruction of North American Pleistocene Ice Sheets with Keewatin center and Labrador center shown as attaining simultaneous maxima. Further explanation in text. (U.S. Geological Survey).

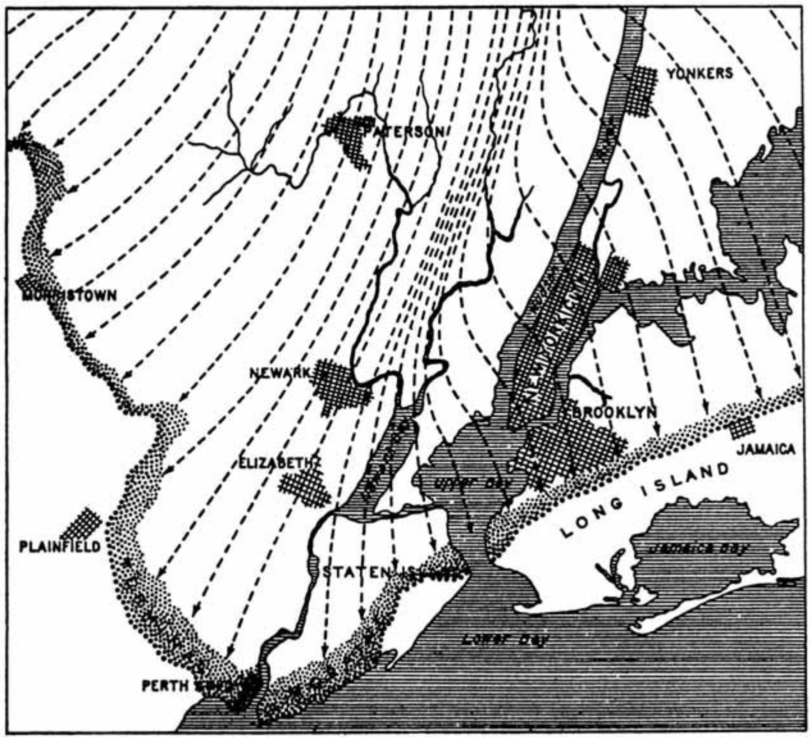


Figure 12 - Map of northeastern New Jersey and southeastern New York showing inferred flow lines in the latest Pleistocene glacier. From U.S. Geological Survey, Passaic Folio, No. 157, Figure 11, 1908, rendering of R. D. Salisbury.

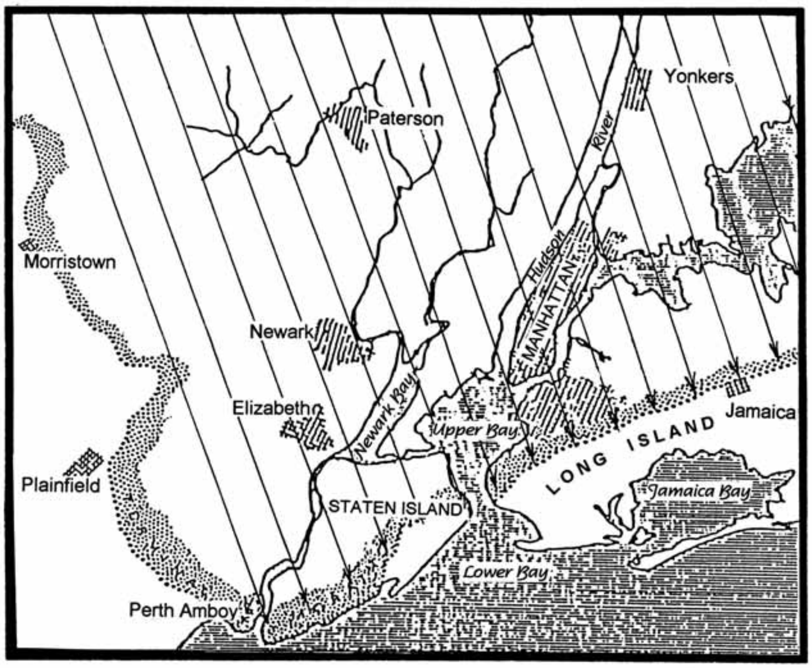


Figure 13 - Rectilinear flow from NW to SE of glacier older than the latest Wisconsinian. This glacier flowed across the Hudscon Valley and deposited red-brown till and outwash on the east side of the Hudson River. Drawing by J. E. Sanders.

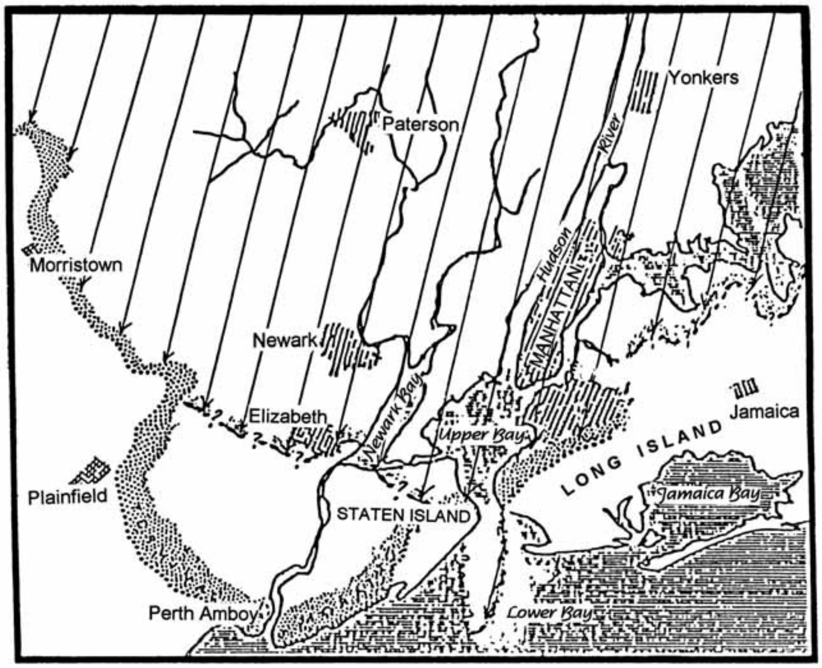


Figure 14 - Inferred flow pattern of latest Wisconsinian glacier, down the Hudson and Hackensack lowlands from NNE to SSW. This glacier affected only the westernmost parts of Long Island; elsewhere, its terminal moraine was along the S coast of Connecticut. Drawing by J. E. Sanders.

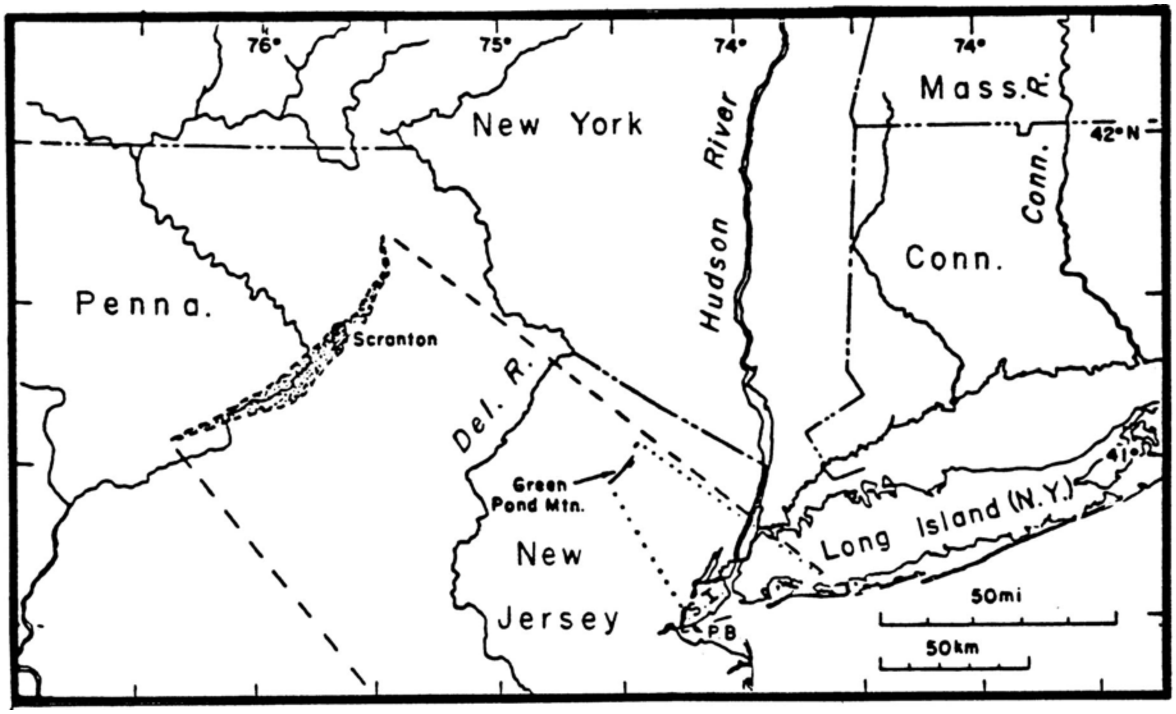


Figure 15 - Distinctive erratics found in till in New York City, (1) anthracite from northeastern Pennsylvania, and (2) Green Pond Conglomerate from northern New Jersey, support interpretation of rectilinear flow of glacier from NW to SE. Stippled area, outcrops of anthracite coal; S.I. = Staten Island, P.B. = Princess Bay. From Friedman and Sanders, 1978, Figure 2-1, p. 27).

The stratigraphy of glacial deposits is worked out by noting the relationships among till, outwash, and sediments that have nothing at all to do with a glacier and, in fact, were deposited under a climate regime that is nonglacial. In a coastal area such as New York, glacial deposits are interstratified with marginal-marine deposits. This has resulted from the relationship between growth of continental ice sheets and the volume of water in the ocean basins. Professor R. A. Daly, of Harvard, once described this relationship between glacial ice and the water of the oceans as one of "robbery and restitution." By robbery, he meant the locking up of the water in the glaciers. By restitution, he meant the return of the water to the oceans when glaciers melted. Although the exact climate setting involved in these changes are not as well known as one might suppose, it is well established that when the glaciers reached their maximum extents, the sea was at its lowest stand, a level around 75 m lower than now.

In addition to ripping up individual fragments from the material over which it passes, a glacier may also deform the strata it overrides. One of the Pleistocene glaciers profoundly affected some of the Upper Cretaceous strata: it stripped several large thin slabs (up to 0.5 km in one dimension and a few tens of meters thick) away from their pre-glacial positions and incorporated them as great thrust slices in the till as seen on Staten Island (On-The-Rocks Trips 05 [Spring 1989], and 19 [Fall 1991]).

On this weekend's field trip we will see evidence for glaciation in the form of glacially sculpted rock surfaces, enlarged stream valleys, drumlins (aligned hills composed of till many sporting apple orchards), and ancient glacial lake deposits. Now on to the primary objectives of this weekend's field trip.

OBJECTIVES

1) Examine the stratigraphy of southeastern New York.

2) Understand the complex structure and history of faulting in southeastern New York.

3) Discuss the "Taconic controversy".

4) Examine and compare correlative bedrock units northward from New York City.

5) Discuss olistostromes, mélanges, and turbidites with particular reference to the Poughkeepsie mélange.

6) Identify and examine the Taconic unconformity.

7) To appreciate the change in metamorphic grade across the Taconide zone

8) To discuss plate models for the development of the Taconic range, and identify the probable source area of the Taconic strata.

ROAD LOG AND INDIVIDUAL DESCRIPTIONS OF LOCALITIES (STOPS)

NYAS to NYS Thruway (I-87) via the George Washington Bridge (GWB) and Palisades Interstate Parkway (PIP). A detailed roadlog, for your driving and reading pleasure, will begin after Stop 1. Figure 16 is a physiographic diagram which has been altered to show major highways and our field trip stops. For now, just a few general comments on what you will see between the NYAS and Stop 1 during our morning drive.

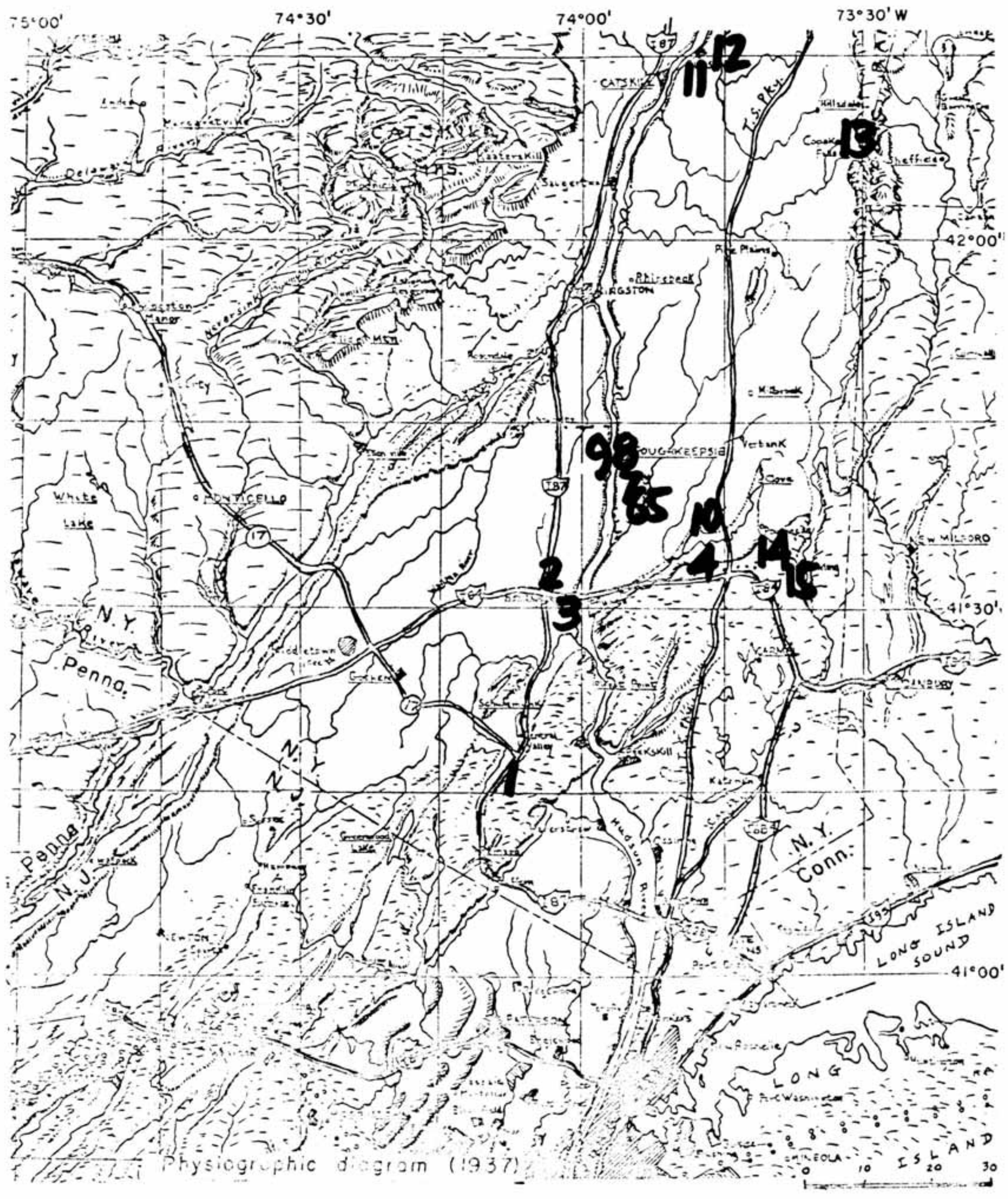


Figure 16 - Physiographic diagram of our field trip route showing Stop numbers 1 through 15. Drawing by F. P. Conant, Wesleyan University, 1937.

Driving northward from the NYAS we travel upon the deeply eroded roots of the Appalachian mountain belt. In New York City, the southern terminus of the Manhattan Prong physiographic province (Figure 7), the bedrock consists of the Proterozoic Fordham Gneiss, overlain by the Cambro-Ordovician Inwood Marble, various tectonostratigraphic units of the Manhattan Schist, and allochthonous rocks of the Hartland Formation. Figure 17 is a geologic map of Manhattan and Figure 18 is a cross section across the Manhattan-Bronx border. Together, they illustrate the structure and stratigraphy of New York City as mapped by CM. On our current trip to the Taconics, we will examine less- metamorphosed correlatives of the crystalline rocks that are beneath us here on Manhattan.

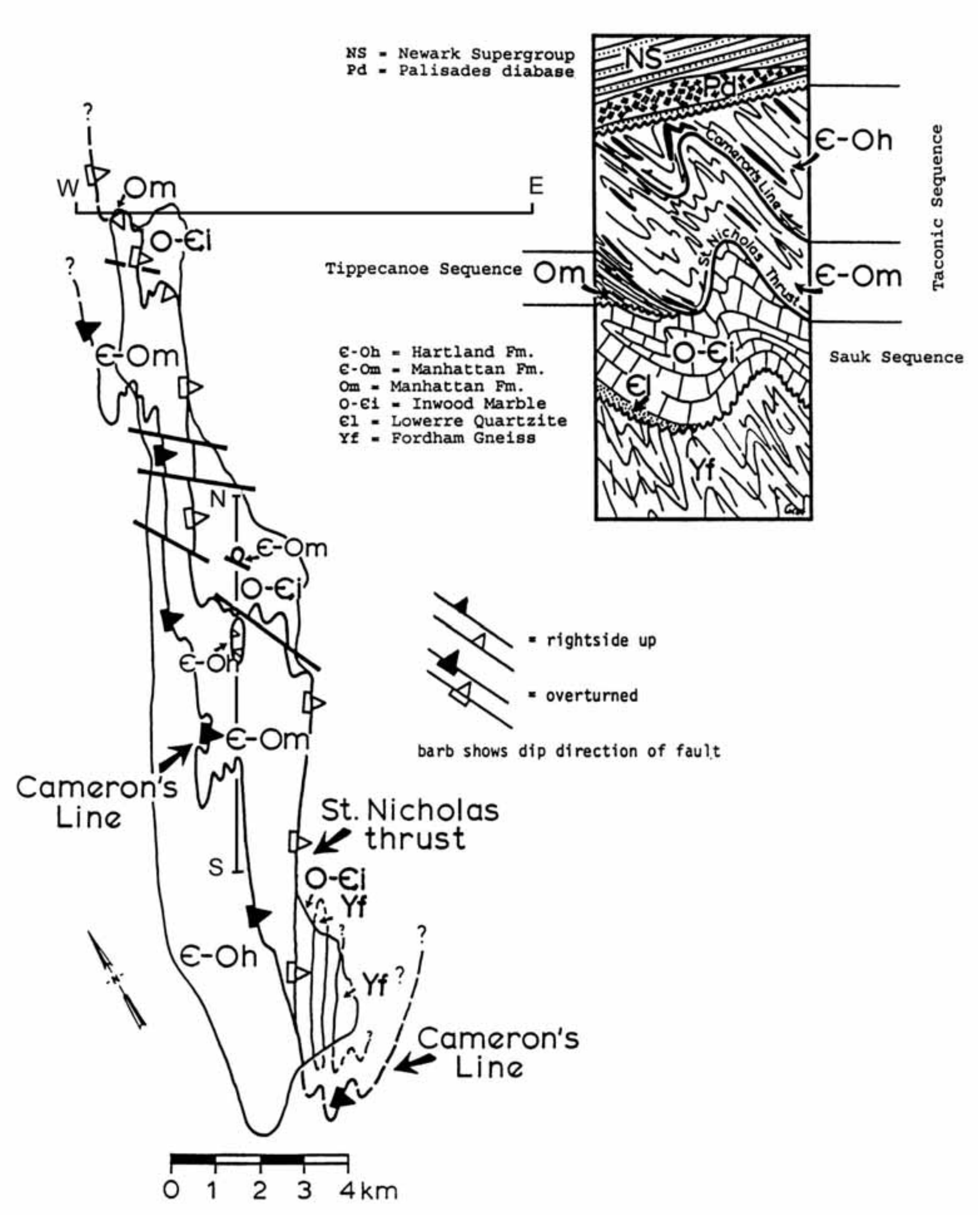


Figure 17 - Geologic map of Manhattan Island showing a new interpretation of the stratigraphy and structure of the Manhattan Schist. Drawn and mapped by C. Merguerian.

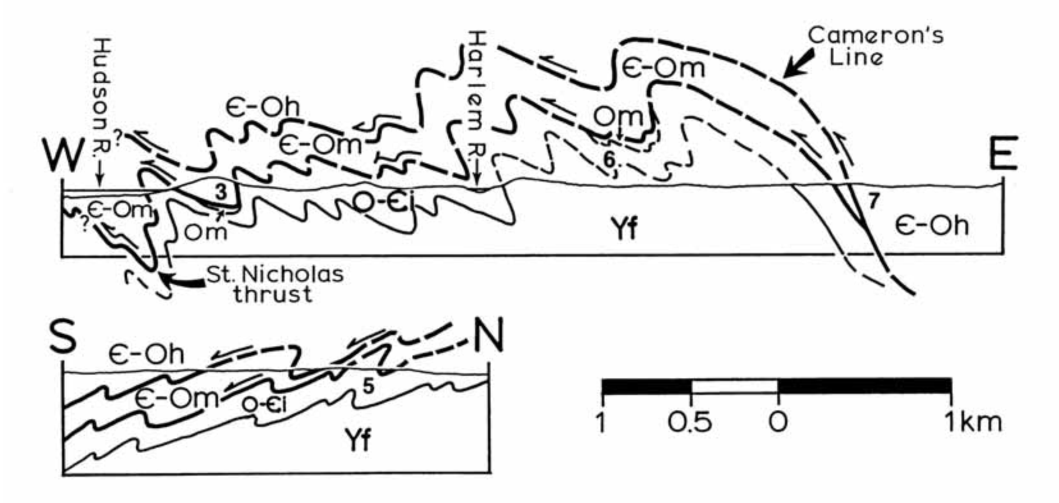


Figure 18 - Geologic cross-section, keyed to previous figure, showing an interpretive west-east structure section across northern Manhattan and the Bronx. Drawn by C. Merguerian.

Driving across the George Washington Bridge we pass from the Early Paleozoic rocks of New York into the Mesozoic rock strata of New Jersey. Figure 19 is a diagrammatic cross section showing the folded rocks of New York City unconformably overlain by gently west-dipping, red-colored sediments and intercalated Palisades Sill of the Newark Basin (On-The-Rocks Trips 05, Spring 1989 and 20, Fall 1991). Driving northward on the PIP, all of the roadside cuts are mafic rocks (diabase) of the Palisades Sill.

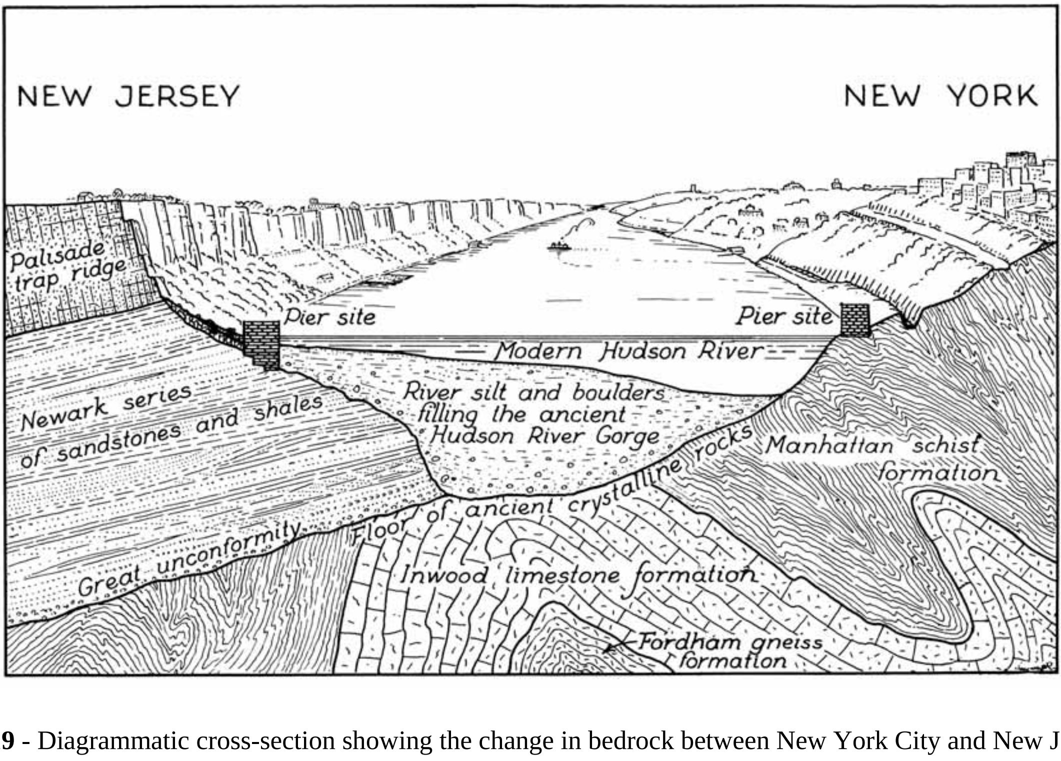


Figure 19 - Diagrammatic cross-section showing the change in bedrock between New York City and New Jersey beneath the George Washington Bridge. From Berkey (1948).

Starting at the cloverleaf where we exit from the PIP to I-87, note the Newark conglomerate in cuts on right. Followed by more Newark conglomerate, within 1.2 mi. on right. In 3.7 mi. note the high cut of Proterozoic rocks from Ramapo Mountains block on right. Here we cross the Ramapo Fault along the NW margin of the Newark basin. Roughly 8.2 mi. from the PIP-Route I-87 intersection, pull into the Sloatsburg service area for Stop 1.

STOP 1a - Proterozoic metasedimentary, granitic-, and dioritic gneiss of the Hudson Highlands, Sloatsburg Service area, I-87N. [UTM Coordinates: ~568.1E / 4556.05N, Sloatsburg quadrangle.]

Grenville-aged (1.1 Billion year old) granitic gneisses of the Hudson Highlands complex form the basal layer (Layer I in Table 2) in the New York area. In the vicinity of New York City we call the age equivalent of these rocks the Fordham Gneiss (as discussed on Field Trip 16 - Spring 1991). Here, the Grenville basement is well-exposed along the east wall of the Sloatsburg Service area of I-87N as hornblende-bearing granitic gneisses that are locally migmatitic (show evidence of partial melting) and cut by numerous faults (with at least three different orientations), as well as a series of joints. The intersection of joints and faults create blocs that are generally rust colored because of the weathering of iron-bearing sulphide minerals such as pyrite. The faults are distinguished from joints in that they show visible offset and often show slickensides (mineralized gouge developed along the bounding rock surfaces). The joints are often tight (and, by definition, show little or no displacement) but are commonly mineralized by fine intergrowths of mica, zeolite minerals, epidote, calcite, quartz, and pyrite, or mixtures of the above.

Interlayered within the main mass of the granitic gneiss are layers and lenses of dark-colored amphibolite and light green diopsidic calc-silicate rock. The probable parent rock (protolith) of the granitic gneisses are granite plutons, and/or quite possibly volcanic ash deposits and/or feldspar-rich greywackes. The calc-silicate rocks began life as carbonate-rich sediments and amphibolites are probably metamorphosed basaltic extrusives or calcareous, iron-rich (ferruginous) shales. As such, the overall stratigraphic sequence idealizes our concept of pre-metamorphic continental crustal rock and overlying shallow- water sediment of the cratonic realm.

The parallelism of the gneissic layering among the granitic gneiss, amphibolite, and calc-silicates suggests that these units were deformed together during an episode of ductile deformation. Such deformation occurs beneath the ductile-brittle transition or at depths equal to, or greater than 10-15 km. The generally low dips of the gneissic layering is typical of the exposures of Grenville-aged basement (or craton) in this part of southeastern New York. Later, as we drive northward, note the sub-horizontal attitude of the gneissic layering in most exposures of Proterozoic gneiss.

These observations lend support to modern contentions that basement rocks deform in huge subterranean overthrusts along shallow-dipping thrust surfaces with ductile metamorphic fabrics developed parallel to the movement surfaces. Also note how, locally, the gneissic layering has been folded by open to crenulate folds fostered by changing motions along the thrusts or entirely younger deformation. Do not confuse the ductile fabrics (metamorphic fabrics) with the younger, superimposed brittle fabrics (faults and joints) which chop the outcrop at typically high angles to form blocky, jagged surfaces. This part of the Appalachians experienced numerous phases of steep, brittle faulting and jointing after the development of metamorphic (ductile) fabric elements, a fact that we will address later in the field trip.

Locally, the highly deformed gneissic layering has been cut by granitic rocks that are themselves foliated to a lesser degree. These appear in many places along the outcrop and show discordant relationships with the gneissic layering. What is more, these late granitoids show very coarse to pegmatitic textures with enormous (up to 10 cm) crystals of hornblende and include xenoliths (foreign rocks) of foliated gneiss.

In the center of the exposure note the steep post-Grenville mafic dike that contains no vestige of metamorphic fabric but is cut by the same brittle features found throughout. Based on regional mapping, these mafic dikes are either lamprophyres of Ordovician age (related to the Taconic Orogeny) or basaltic dikes of Mesozoic age (related to rifting and development of the Newark Basin, as discussed on Trip 20 - Fall 1991). At the north end of the exposure note the increase in graffiti! Clearly this is an example of how country rock begins its transition into city rock as discussed in great detail on On-The-Rocks Trip 02, Fall 1988!

The following road log is meant to be read while we drive between stops. To help you in the event you attempt this trip on your own, actual mileages from Stop 1 are given (first stop beginning with 0.0).

Mileage	**Remarks**
[0.0]	Thruway on bridge over Johnstown Road.
[0.4]	Large cut of Proterozoic rocks on R.
[0.5]	End of cut.
[1.0]	More Proterozoic country-rock gneisses with low foliation dips.
[1.4]	County boundary; leave Rockland County, enter Orange County.
[2.5]	More Proterozoic gneisses in low cut.
[3.1]	Proterozoic mafic gneisses; glacial sculpting of rock at left of road.
[3.5]	Foliation in gneiss dips about 45°.
[3.8]	Proterozoic rocks exposed on both sides of Thruway; granitic sills (with pink feldspar) crosscut mafic gneisses.
[4.2]	Thruway passes through open valley; no roadcuts here.
[4.4]	Proterozoic rock on R. Ramapo River on L.
[4.5]	Thruway crossing bridge over Greenwood Lake Road.
[5.3]	No cuts for a stretch.
[6.4]	Thruway passes beneath bridge of local road above.
[6.5]	Leave Sloatsburg quadrangle; enter Monroe quadrangle.
[7.1]	Low cut on R dark-colored Proterozoic gneiss.
[7.8]	Thruway passing beneath bridge for local road and for Appalachian Trail passing above.
[7.9]	Cut on R newly fenced from highway; dip of foliation is steep to E.

[8.4] House on R in open, rolling fields. The bedrock consists of Paleozoic carbonates in a feature named the Thruway graben by Jaffe and Jaffe (1973). See also: (Dodd, 1965 and Offield, 1967).
[9.1] Cuts on R. (Pull-over Stop #1) display Paleozoic carbonate rocks (protolith of the Inwood Marble).

Pull-Over Stop 1b - Carbonate rocks of the Sauk Sequence cut by mafic dikes on Route I-87N (10.2 miles north of STOP 1). [UTM Coordinates: 571.8E / 4570.3N, Monroe quadrangle.]

State law precludes stopping to look at rocks on I-87 so this pull-over stop will be discussed in the van - eyes right! After numerous miles of Proterozoic gneiss exposure on I-87N we have now passed into a major graben [down-dropped block with normal (gravity) faults on each side] that exposes Cambrian to Ordovician limestone and dolostone. Here the well-layered, whitish to tan-weathering dolostone dips to the east with a strike parallel to the highway (same as the foliation in the Proterozoic gneiss!). Of additional interest here is the tan-weathering ferroan dolomite, algal laminae, and a mafic dikes that cut angularly across the bedding of the carbonate rock and in places include angular xenoliths of the carbonate host rock. This discordant relationship plus isotopic data (Ratcliffe and others, 1983) suggests that the mafic dike in this outcrop is post-Ordovician in age.

[9.3] Cambro-Ordovician carbonates, in down-faulted block (the Thruway graben of Jaffe and Jaffe), form a more-open countryside that has been cleared; the slopes are gentler and the soil more fertile than in areas underlain by the Proterozoic rocks.
[10.1] Low ledge of Cambro-Ordovician carbonates exposed in field on R. (outcrop is covered by graffiti). This is another vain attempt of the country rock trying to look like city rock!
[10.9] Thruway passing under bridge for road to Arden House (former Harriman estate; now Columbia University conference center).
[11.6] Toll gate at Exit 16, Harriman.
[12.2] Leave Monroe quadrangle; enter Popolopen Lake quadrangle.
[12.5] Slope on R. underlain by till.
[13.0] Thruway passing under bridge for old US Route 6 at Camp Wildwood (on W side of Thruway). The lowland on the L (W) marks the divide between drainage that flows N and into the Hudson via Woodbury Creek and Moodna Creek, and that which flows S via the Ramapo River. The Ramapo has cut through the rocks of the Hudson Highland and eventually drains into lower New York Harbor. The town of Central Valley occupies the low area of the divide.
[13.7] Thruway passing under bridge for Smiths Clove Road.
[13.8] Cambro-Ordovician carbonates on R dip steeply to the SE. High ridge ahead is Schunemunk Mountain [location for On-The-Rocks Trip 09 (November 11, 1989)], underlain by Middle Devonian conglomerates.
[14.2] Cambro-Ordovician carbonates on R, just S of bridge.
[14.3] Thruway passing under bridge for Pine Hill Road.
[14.4] Red siltstone on R. is part of the Longwood Shale, of Silurian age (probably equivalent to the High Falls Shale of the central Hudson Valley and the Bloomsburg Formation of the central Appalachians). The underlying Green Pond Conglomerate is faulted out of the roadcut

exposures, but is present to the northeast. This exposure is very significant in that it is the only place in New York State where the Green Pond Conglomerate is present.

[14.5] Strata dipping steeply NW are of Devonian age (part of the Highland Mills succession described by Boucot, Gauri, and Southard, 1970 - see Table 4). The coarse white sandstone at left is the "Oriskany" of older stratigraphers; in the post-Boucot era, the terms used are Connelly Conglomerate and Central Valley Sandstone.
[14.6] Devonian strata exposed in cuts on both sides of the Thruway.
[15.1] End of cuts in Devonian rocks.
[15.2] Till on right of Thruway; bedrock not visible.
[16.0] Thick till on R.; two half-drumlins ending on the S against a narrow ridge underlain by Lower Silurian Green Pond Conglomerate on SE limb of Idlewild (=Mountainville) syncline.
[16.3] Thruway passes above NY Route 32 (Albany Turnpike). On R., in Town of Woodbury, the belt of Devonian strata ends by being faulted against Proterozoic gneiss. JES thinks this fault contains a strike-slip component and that it may be of post-Newark (mid-Jurassic) age (but no proof exists for this interpretation).

[16.6] Leave Popolopen Lake quadrangle; enter Cornwall quadrangle.
[18.6] To W of Thruway is NE end of Schunemunk Mountain.
[18.9] Star Manufacturing Co. on R., in town of Mountainville.
[19.2] Thruway passing under bridge for Taylor Road.
[19.4] Thruway bridge crossing Moodna Creek.

The Catskill aqueduct crosses the valley of Moodna Creek with a pressure tunnel. According to Berkey (1933, p. 102):

"Great difficulty was experienced in obtaining the required information in this valley. In no other, except the Hudson gorge itself, was it found so difficult to determine the profile of the rock floor and the underlying structure. The overburden of glacial drift carried unusually large boulders, making the boring program difficult and expensive. For a considerable distance in the bottom of the valley the cover is 300 feet (91 meters) deep, and one of the borings penetrated a single boulder 34 feet (10 meters) through, lying in the drift 100 feet (30 meters) above the floor."

The geologic structure was finally unraveled and the surprising result was the discovery of narrow faulted slices of the Proterozoic gneisses. "The strip of ancient gneiss which had been looked for as a continuation of the Snake Hill ridge was located by exceptionally successful exploratory borings but proved to be surprisingly narrow...Heavy crush zones, indicating displacement, were found on both sides of the strip of gneiss. Both zones stand at comparatively steep angles and are in poor condition, and required timbering. The tunnel actually penetrated only about 500 feet (152 meters) of gneiss or granite..."

"It was shown that displacements of two periods are represented--a thrust fault of Appalachian type and a block fault of Triassic age. The two displacement lines strike so nearly parallel that long slivers of ancient rocks are left stranded out in areas of Paleozoic strata..."

[19.7] Thruway passes beneath bridge for Pleasant Hill Road. This place is notorious because the shoulders of the Thruway can accommodate State Troopers' radar patrol cars and the chaser cars to catch the speeders.
[20.3] Clear day view of Storm King, Hudson Highlands, on R.
[20.9] Thruway passes beneath bridge for Orrs Mill Road. Ridge on L (west) is underlain by Silurian rocks.
[21.3] Thruway crosses above railroad tracks. On W (left) is the northeast end of the Idlewild (=Mountainville) syncline. Here, the Lower Silurian Conglomerate rests on the Middle Ordovician Martinsburg Formation. The nature of the contact is not known; it could be one of unconformity or a fault.

[22.5] Thruway passes over NY 94, just W of Vails Gate. The New York State Geologic map shows a fault block of Proterozoic rocks, about 500 feet wide, beneath the Thruway here. This mapping is based on the borings for the Catskill Aqueduct (Berkey, 1933, p. 101-105; Plate 12, following p. 98). See Berkey and Holzwasser profile-sections and keyed map (Figures 20, 21, 22) for geologic relationships determined in this vicinity when the Catskill Aqueduct was built and during later mapping.
[22.7] Thruway passes over railroad.
[22.8] Thruway crosses over Catskill Aqueduct.
[22.9] In the straight stretch for the next 1.5 miles, the Thruway parallels a pair of large drumlins on the L. (SW). The long axes of these drumlins trend N20°W - S20°E.
[24.4] Covered contact between Cambro-Ordovician carbonates and Middle Ordovician Martinsburg Formation.
[24.9] Thruway bridge over NY Route 207.
[25.3] Lake Washington on R. (E).
[25.7] Crossing thrust fault of Cambro-Ordovician carbonates against Middle Ordovician Martinsburg Formation.
[26.4] Leave Cornwall quadrangle; enter Newburgh quadrangle.
[26.5] Take exit ramp on R for Exit 17. Keep R for ramp to I-84, eastbound. Pull-over at large cut on I-84 at base of ramp.

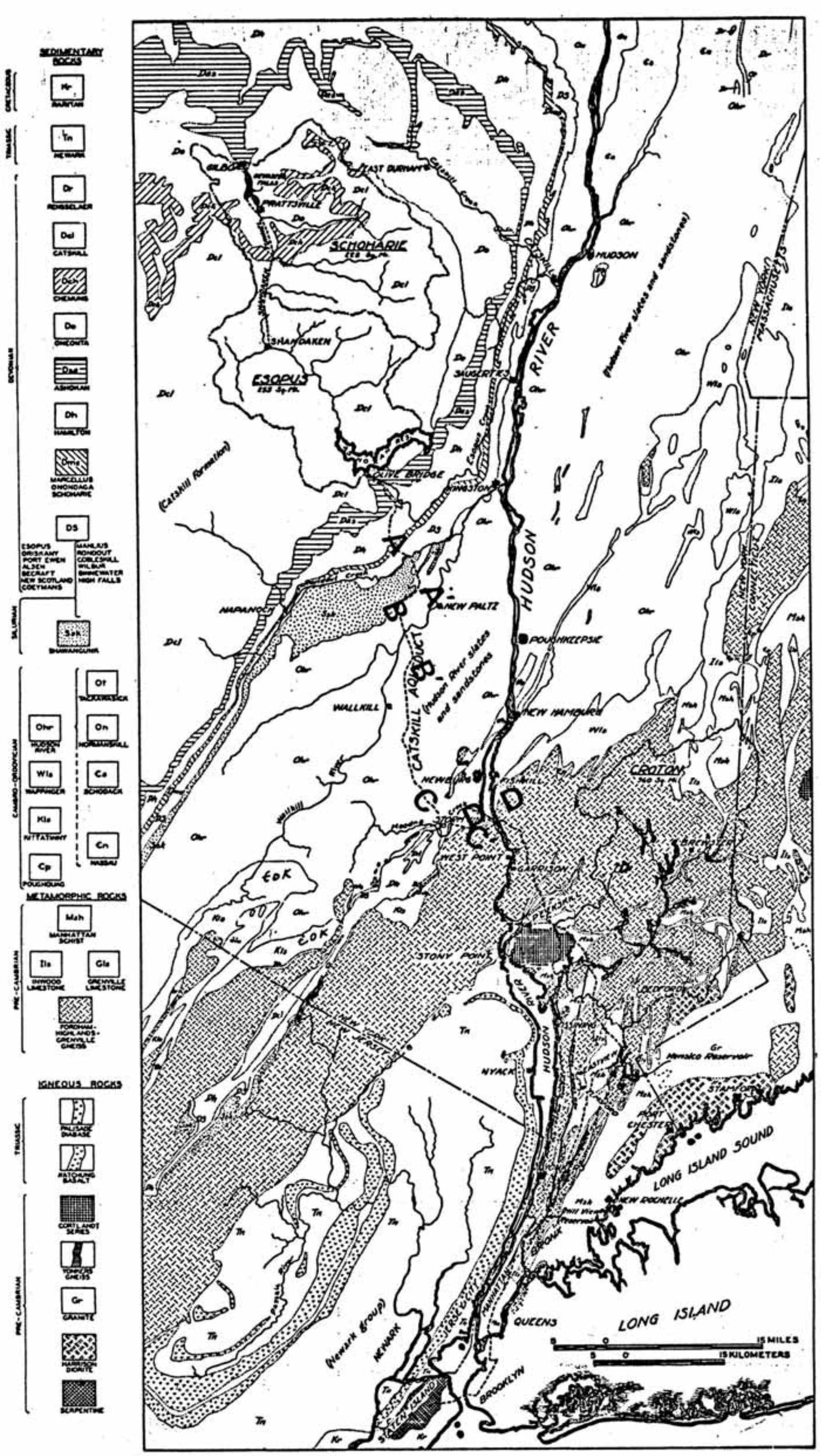


Figure 20 - Geologic sketchmap (from Berkey, Plate 9, 1933) showing the positions of cross-sections of Figures 21 and 22.

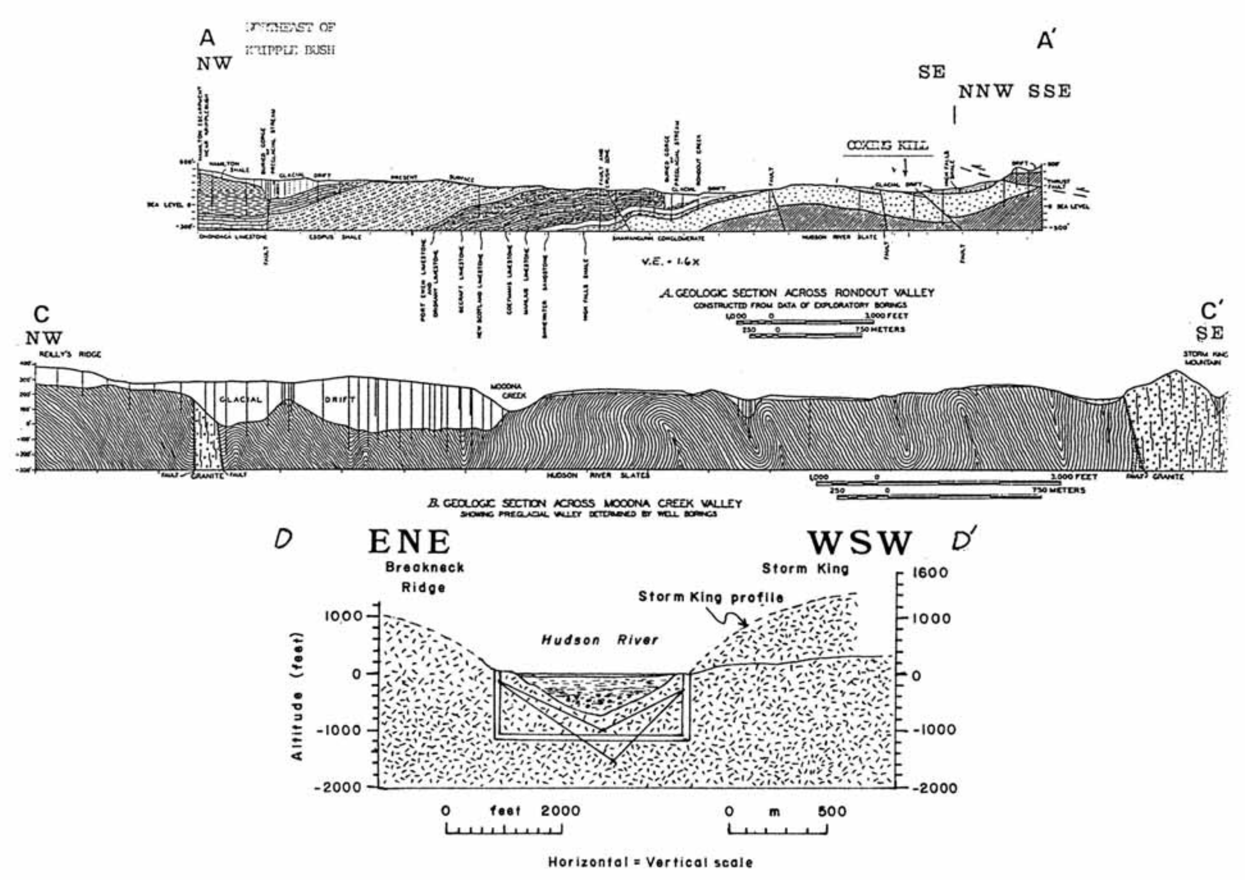


Figure 21 - Geologic cross-sections (A-A', C-C', and D-D') of the Hudson Valley, New York (keyed to Figure 20) from Berkey (1933).

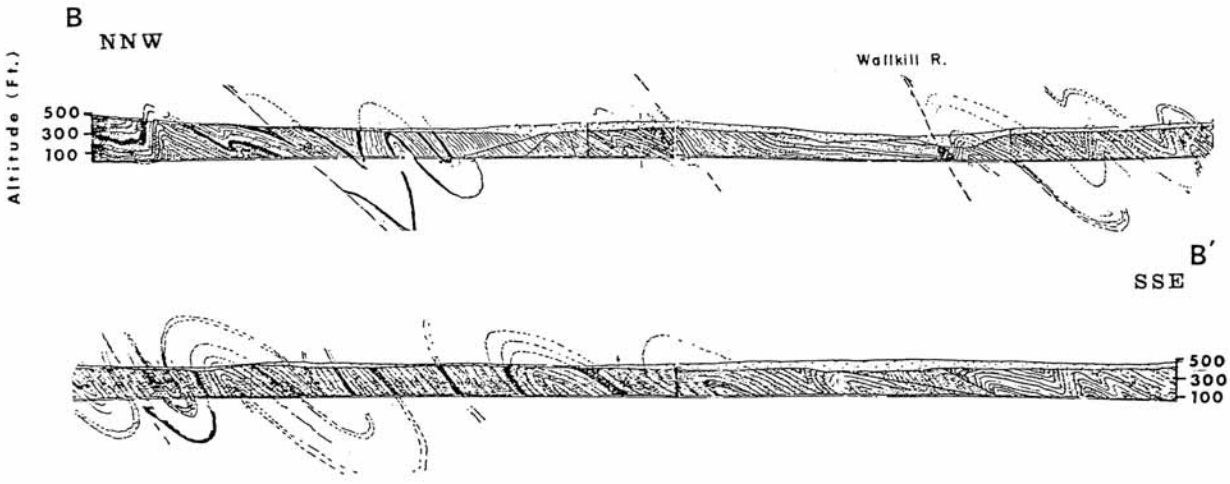


Figure 22 - Geologic cross-section (B-B)' of the Hudson Valley, New York (keyed to Figure 20) from Holzwasser (1926) [as redrawn by JES].

Pull-Over Stop 1c - Route I-84E, just off exit ramp from I-87N. Nonconformable contact between Proterozoic gneiss and overlying Cambrian Lowerre quartzite. [UTM Coordinates: N/A, Newburgh quadrangle.]

For the same reason outlined above, as well as poison ivy, ticks, and a rare siting of the boogeyman, we will also examine these rocks from the van - eyes right! The geology of this area was mapped by Holzwasser in 1926. This site is famous for its rare glimpse at the basal contact of the Paleozoic shelf sequence (Layer IIA(W) of Table 2) where it rests depositionally upon the eroded Proterozoic in spectacular angular unconformity (Hutton would be proud of this one!). Across I-84 (eyes left!) the outcrop is also composed of graphite-bearing Proterozoic gneiss which dips gently toward and beneath us. Here, the Proterozoic is faulted against the Middle Ordovician Martinsburg Formation.

Exposed along the north-facing wall (eyes right!) the Lower Cambrian Poughquag Quartzite [equivalent to the Lowerre Quartzite in New York City (see Table 2)] rests nonconformably above the Grenville basement gneisses (see sketch in Figure 23). Note how the layering in the Grenville gneiss is truncated at an acute angle against the surface of nonconformity (conveniently marked by the east-dipping poplar tree root), whereas the layering (bedding) in the massive quartzite is parallel to the surface of nonconformity. The root of the problem in Appalachian geology is that critical contacts (like this one) have been commonly eroded away or covered by younger rocks or soils.

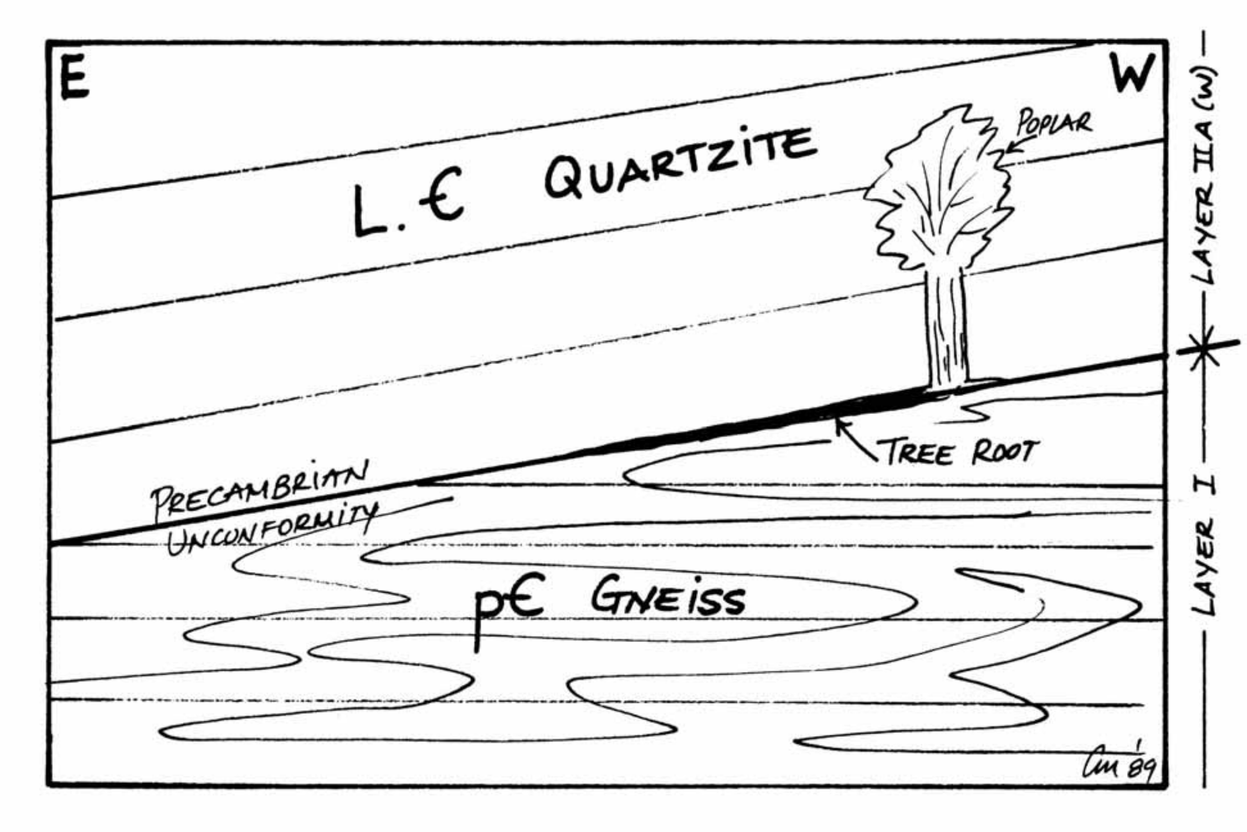


Figure 23 - Geologic sketchmap of Proterozoic - Paleozoic unconformity exposed at Pull-over Stop #2.

Here, the basal part of the Lower Cambrian Poughquag (see evergreen in sketch) is noticeably pebbly and this grades upward into massive, blocky orthoquartzite that is typical of the Lower Cambrian in southeastern New York. These Lower Cambrian clastics began life as pebbly to sandy quartz sandstones. Up the hill and to the east, are Sauk Sequence (Cambrian to Ordovician) carbonates. Note that the rocks in this exposure have been cut by high-angle brittle faults. Many high-angle faults disrupt the sequence to the east; see if you can spot them as we drive on.

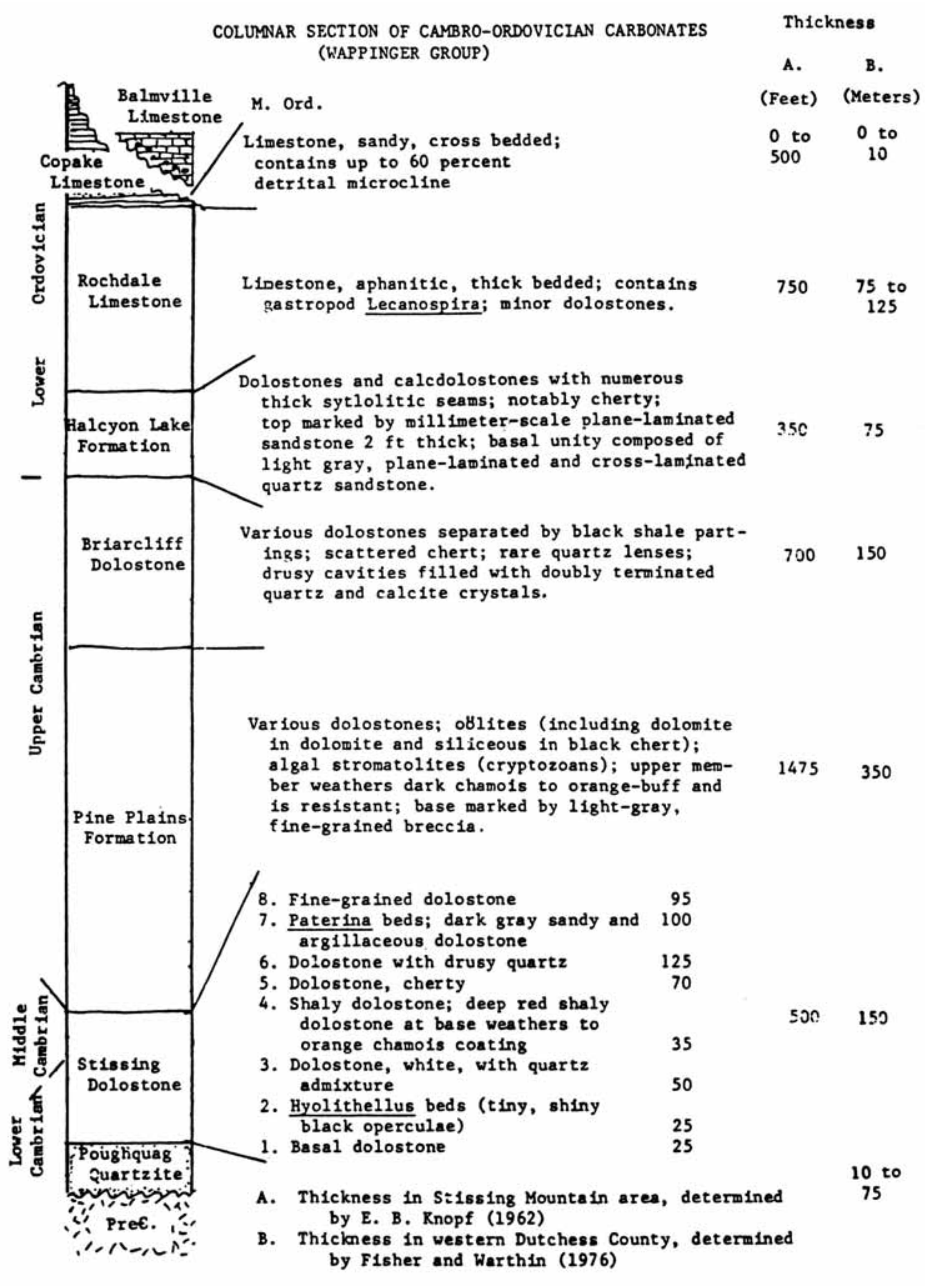
[28.1] Continue E on I-84.
[30.4] Ramp for Exit 10 on R; in cuts on both sides of the road are Sauk Sequence carbonates, probably from the Pine Plains Formation.
[30.8] At bottom of ramp, turn L at traffic light. Drive under I-84. Keep L for another L turn at next light.
[30.85] Turn L on NY 32; keep R to enter parking lot for Perkins Pancake House. Pit stop, etc., if needed.
[31.2] Walk across NY 32 at traffic light for Stop 2, Sauk Sequence (Cambro-Ordovician) dolomitic carbonates.

STOP 2 - Sauk Sequence of central shelf: Wappinger Group (Cambrian - Ordovician) carbonates. [UTM Coordinates: N/A, Newburgh quadrangle.]

Across from the parking areas of Perkins and Burger King occur large cuts of Wappinger carbonates of Cambrian to Ordovician age. These essentially non-metamorphosed rocks are similar to rocks of pull-over stop #1 and correlative protoliths and age equivalents of the Inwood Marble of New York City, the Woodville Marble belt of western Connecticut, and the Stockbridge Marble of western Massachusetts. Figure 24 is a columnar section of the Cambro-Ordovician carbonates of the Wappinger Group. Taken together, these carbonate units constitute the shallow-water Cambrian to Ordovician North American passive-margin carbonate-shelf strata that overlie the Lower Cambrian clastics (originally sandstones of Layer IIA(W) in Table 2). In addition, these rocks are lithically equivalent to those found (not in situ, of course!) by veteran On-The-Rockers on the On-The-Rocks Trip 07 (Fall 1989) to Robert Moses State Park. At Democrat Point, these carbonate blocks were used to construct the jetty.

Here, the Wappinger carbonates form a well-layered, east-dipping sequence with meter-scale interbedding of dolostone, oolite, and chert with dark-colored ribbony solution residue (stylolites) generally parallel to bedding. The light-colored to dark-colored to tan interbeds are compositional alternations between carbonate sand to carbonate mud to ferroan dolostone, respectively. The stylolites resulted from burial and fluid transfer leading to dissolution of carbonate and formation of clay-rich residues along zones of solution. In areas where the stylolites become thicker, they take on the appearance of shaly partings; however, it must be appreciated that these layers are not depositional (primary) but, rather, secondary in nature. At higher temperatures and pressures (greater depth of burial), these shaly partings begin to metamorphose with the growth of mica and thus serve as indicators of metamorphic grade. This will become obvious at the end of Day 2 if we are able to examine metamorphosed equivalents of these Sauk Sequence rocks farther east (Unofficial Stop 15).

Other features of interest at this exposure include channels (possible slump features?), boudinage of dark carbonate and chert layers due to ductility contrast, low-angle thrust faults, as well as high-angle, locally faulted, contacts. Again, the high- angle faults are well developed in the region and displace numerous blocks of bedrock. At the end of Stop 2, reboard vans.



COLUMNAR SECTION OF CAMBRO-ORDOVICIAN CARBONATES
(WAPPINGER GROUP)

		Thickness A. (Feet)	Thickness B. (Meters)
Balmville Limestone	M. Ord.		
Copake Limestone	Limestone, sandy, cross bedded; contains up to 60 percent detrital microcline	0 to 500	0 to 10
Rochdale Limestone	Limestone, aphanitic, thick bedded; contains gastropod Lecanospira; minor dolostones.	750	75 to 125
Halcyon Lake Formation	Dolostones and calcdolostones with numerous thick sytlolitic seams; notably cherty; top marked by millimeter-scale plane-laminated sandstone 2 ft thick; basal unity composed of light gray, plane-laminated and cross-laminated quartz sandstone.	350	75
Briarcliff Dolostone	Various dolostones separated by black shale partings; scattered chert; rare quartz lenses; drusy cavities filled with doubly terminated quartz and calcite crystals.	700	150
Pine Plains Formation	Various dolostones; oölites (including dolomite in dolomite and siliceous in black chert); algal stromatolites (cryptozoans); upper member weathers dark chamois to orange-buff and is resistant; base marked by light-gray, fine-grained breccia.	1475	350
Stissing Dolostone	8. Fine-grained dolostone 95 7. Paterina beds; dark gray sandy and argillaceous dolostone 100 6. Dolostone with drusy quartz 125 5. Dolostone, cherty 70 4. Shaly dolostone; deep red shaly dolostone at base weathers to orange chamois coating 35 3. Dolostone, white, with quartz admixture 50 2. Hyolithellus beds (tiny, shiny black operculae) 25 1. Basal dolostone 25	500	150
Poughquag Quartzite			10 to 75

A. Thickness in Stissing Mountain area, determined by E. B. Knopf (1962)
B. Thickness in western Dutchess County, determined by Fisher and Warthin (1976)

Figure 24 - Columnar stratigraphic section of Cambrian to Ordovician carbonates of the Wappinger Group (Friedman and others, 1982).

[31.3] Turn L out of parking lot and keep R for R turn at traffic light.
[31.5] Turn R on US Route 9W and drive under I-84; keep L for upcoming L turn.
[31.6] Turn L for entrance to I-84, eastbound.
[32.0] Just beneath first overpass, pull over to R and park for Stop 3, red and green slates, thin carbonates, etc. of the Taconic Sequence (Cambrian-L. Ord.).

STOP 3 - Varigated red and green to gray Taconic slates on Route I-84E, Fishkill, New York. [UTM Coordinates: N/A, Newburgh quadrangle.]

In the only known (at least to JES and CM) occurrence of Taconic slates found to the west of the Hudson River in New York State (there are others in New Jersey and Pennsylvania), the outcrops exposed here show rocks typical of the Taconic allochthon (a fancy word intended to impress people at cocktail parties meaning "not found where originally deposited"!). As discussed earlier, the "Taconic Problem" revolves around the recognition of Cambrian to Ordovician slope/rise to deep-water oceanic slates (Layer IIA(E)) which appear structurally above middle Ordovician flysch of Layer IIB (see previous discussion and Table 2). Here, the flysch deposits are not exposed but presumably occur beneath us. Alternatively, in this far westward exposure, the Taconic rocks may rest structurally above the carbonate-shelf sequence but there is no evidence to support this notion.

The slates at the extreme west end of the outcrop are dominantly red colored indicating a large amount of hematite (ferric iron, Fe^{+++}). The interlayered greenish slate contains ferrous iron (Fe^{++}). The greenish slate is similar in texture and color and possibly in composition to volcaniclastic rocks mapped by CM and many others farther north as the Mettawee Slates of the central Taconic range (Figure 3). As such, these rocks may represent volcanic-ash deposits which were interbedded with iron-rich oceanic mudstones. Thus, the Taconic slates here show input from a volcanic source, presumably on the oceanward side of the former depositional site. Immediately east of the overpass, bedding and slaty cleavage occur in parallel orientation with a NE strike and steep SE dip. Two generations of intrafolial isoclinal folds are easily observed at this location. They lie within the slaty cleavage and have both shallow and steep plunges toward the SW. Mapping of Taconic structures elsewhere in the vicinity indicate that these two generations of early isoclinal folds are related to thrusting of the Taconic allochthon and development of the regionally persistent slaty cleavage. Time permitting, we will illustrate the methods of measuring planes (bedding and cleavage) and lines (fold axes) using the Brunton compass.

Farther east along the exposure the color changes to dominantly grey slates and siltstones that are representative of carbonate muds, poor in iron. The field test for slate vs. siltstone, by the way, is to gring a small chip of the material between your teeth. If you feel the slightest grit, the lithology is a siltstone. If the material powders and feels chalky, the rock is a slate (or shale). If your teeth break, you have inadvertently chewed a piece of quartzite of gneiss - oops!. Close examination indicates that truncated ripples occur in the silty layers from which we can interpret stratigraphic top directions. Intercalated with the grey slate occurs cm-scale layers and lenses of hemipelagic limestone (hemipelagic means deep-sea sediments containing a small amount of terrigenous material as well as remains of pelagic organisms). In addition, 10 cm by 40 cm limestone blocks occur at the same location. Close examination indicates that the larger limestone blocks are actually fragmental and contain angular to sub-rounded clasts of limestone. That is, they are actually carbonate conglomerates. These carbonates blocks are interpreted as olistoliths and were probably derived from the shelf edge (continentward source) and slid from the continental rise (possibly by a subaqueous avalanche) into the deep-ocean depositional area of the slates. Thus, during the early Paleozoic, the depositional area of the slates was receiving sedimentary and volcanic material from both continentward and oceanward sources, respectively.

[32.0] Continue across Hudson River. About one-third the way across the river, leave Newburgh quadrangle and enter Wappinger Falls quadrangle. Figure 25 is a geologic map and section essentially parallel to our field trip route for this afternoon. Stops 3 through 10 are plotted on this map which should be consulted as often as necessary. On bridge span, look R for view into Hudson River gorge through the Hudson Highlands. See Berkey profile-section [Figure 21 (Section D-D'), and Figure 26] for geologic relationships determined here when the Catskill Aqueduct was built. The engineering studies for selecting the route for this aqueduct began in 1905. About a year into the operation, in April 1906, to be exact, the San Francisco earthquake and fire shook up more than the city of San Francisco. Because some geologists had been writing that the Hudson River followed a fault, project geologists worried about where the aqueduct could cross the Hudson River without placing it at risk of loss during a sudden shift on a fault. After making many lines of borings, their attention turned to Storm King. They were not able to reach bedrock in the borings made from most of the barges anchored in the river. The deepest boring, to -768 feet, was still in till. Only one of the shallower borings closer to shore reached bedrock (solid granite and no indication of a fault). In order to be certain about the rock conditions here, they excavated two subsurface work chambers out of the granite, one on the E bank and the other, on the W bank. The floors of these work chambers were at -250 feet. In each work chamber, they set up a drilling rig to drill two slanted holes from each side of the river. They aimed these holes so they would intersect beneath the river at -950 and -1500 feet, respectively. When these cores showed nothing but solid granite, they chose this site for the crossing (Figure 26).

The finished pressure tunnel, a huge pipe, 14 feet in internal diameter, and 3,022 feet long, extends beneath the river from a subsea elevation of -1111.0 on the W side to -1114.0 on the E side. During construction, they found the rock to be almost unbroken granite. No water was present; indeed, it was necessary to pump in water to operate the drills that made the shot holes used in blasting out the rock.

[33.8] Toll plaza.
[36.8] Proterozoic felsic gneiss featuring coarse-textured pink feldspar exposed in cuts. JES infers that these rocks are part of the central-shelf pre-Taconic-allochthon overthrusts that have been preserved in a block that was droppped down along post-overthrust, high-angle brittle faults (of Mid-Jurassic age?).
[37.3] Take ramp on R, Exit 12, Fishkill, NY Route 52.
[37.45] At bottom of ramp, turn R, then immediately R again for I-84 Diner. (Rest stop, etc.)

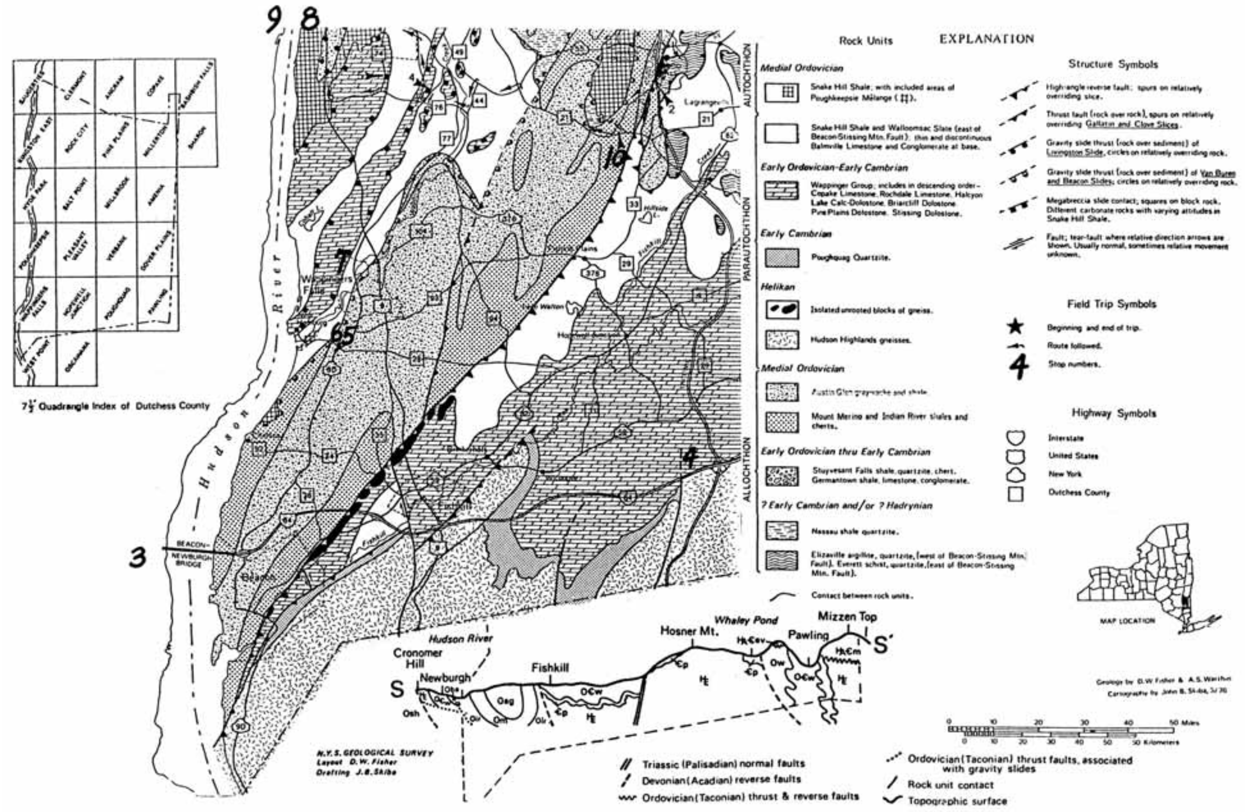


Figure 25 - Geologic map of Duchess County, New York from the New York State Geological Survey.

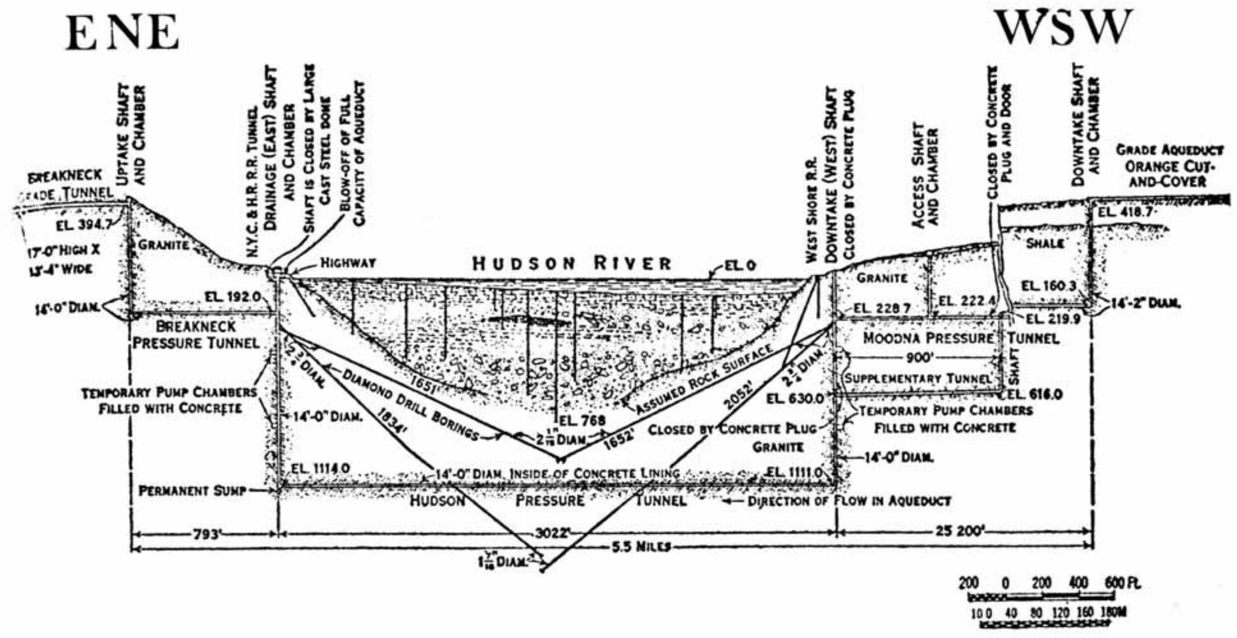


Figure 26 - Cross-section of the Hudson River crossing of the Catskill Aqueduct, looking downstream. From the Encyclopedia Brittanica, p. 567.

Resume Road Log

[37.5] On leaving diner, turn L, but get into R lane for upcoming R turn.
[37.6] Turn R for entrance ramp to I-84, eastbound. High ridges ahead are underlain by resistant Proterozoic rocks.
[39.0] Passing ramp on R for Exit 13, US Route 9. The lowland here, underlain by Cambro-Ordovician carbonates, is crossed by one or more faults. The Honness Mountain block lies to the SE and the North Beacon Mountain block, to the NW. The presence of the Lower Cambrian Poughquag Quartzite and overlying Cambro-Ordovician carbonates on the NW sides of these fault blocks suggests to JES that the adjacent masses of Proterozoic rocks are parts of the great central-shelf pre-Taconic-allochthon overthrusts.

[39.75] Leave Wappinger Falls quadrangle, enter Hopewell Junction quadrangle.
[39.8] Proterozoic gneisses, well-defined foliation dips to N; recumbent isoclinal fold present. Another place where JES infers a remnant of the central-shelf overthrusts preserved on late brittle-fault downdropped block.

[40.2] More of same on R; big cut.
[41.45] I-84 on bridge over Fishkill Hook Road; Cambro-Ordovician carbonates dipping SE on NW limb of syncline.
[41.6] Axis of anticline in Sauk Sequence carbonates on L.; probably the lowest formation, the Lower Cambrian Stissing Formation.
[42.35] Cuts of till; part of a prominent drumlin with long axis trending NW-SE.
[42.55] Powerline crosses overhead of I-84.
[42.65] I-84 on bridge over Lime Kiln Road.
[43.7] Turn R on exit ramp for Exit 15 (no Exit 14), Lime Kiln Road.
[44.1] At top of ramp, turn R onto Lime Kiln Road and cross over I-84. Keep L for upcoming L turn at light.
[44.7] Make U-turn to L at entrance to IBM plant; pull up and park on R for Stop 4, Pine Plains Formation (Upper Cambrian unit of Wappinger Group, Sauk Sequence)

STOP 4 - Sauk Sequence: Pine Plains Formation on Lime Kiln Road. [UTM Coordinates: 598.88E / 4500.13N, Hopewell Junction quadrangle.]

The Pine Plains Formation (Figure 24) was named by E. B. Knopf (1946) when she subdivided the Wappinger Group. [Note: in our 1989 guidebook, we referred these rocks to the Briarcliff Formation. Subsequently, however, studies of the cuttings from the Crom-Wells No. 1 Fee boring in Orange County, NY by Prof. Baiying Guo (of Northeastern Science Foundation, Troy, NY) have shown that the quartz admixture in the Briarcliff consists entirely of silt. Sand-size quartz is not present in the Briarcliff, but is abundant in the Pine Plains Formation. In addition, studies by Guo and JES in the Clinton Point quarry indicate that the well-defined cyclicity, as shown here, characterizes the Pine Plains Formation.] Some aspects of the exposures here have been published in an article by Ervilius and Friedman (1991).

Here, the cyclicity of alternating A-B-A-B facies patterns shows up as light- and dark layers(s) which strike NE and dip NW. Similar to Stop 2 (earlier today), the light-colored layers were carbonate sand and the darker layers consisted of carbonate mud. Layers of chert (siliceous ooze), sandstone, and intraformational breccia are common along the length of the exposure. Symmetrical wave-generated ripples occur with ripple crests roughly parallel to the strike direction. Finely laminated layers are the result of carbonate deposition during the formation of algal stromatolites. In addition, evaporite nodules have dissolved to form micro-geodes now filled with calcite, silica, pyrite, and chalcopyrite (the result of burial and dissolution). Burial has also prompted the development of stylolites as branching layer-parallel dark "injections" (cross-cutting dissolution residues) at all scales.

[44.7] Re-board van; continue S to entrance ramp for I-84, westbound.
[44.9] Take ramp on R to I-84; carbonates here are exposed nearly along strike and thus appear to be horizontal. In actuality, they dip away from the road.
[45.4] On I-84, westbound. Look for cuts of till; part of a prominent cleared drumlin with long axis trending NW-SE. Here, I-84 curves to L. Given good visibility, one can see Honness Mountain ahead. It is underlain by Proterozoic gneisses that are across a fault from the Cambro-Ordovician carbonates underlying this part of I-84.

[46.4] Cuts of Cambro-Ordovician carbonates. I-84 has crossed the axis of a syncline that plunges NE; we are probably in the Stissing Formation.
[46.55] I-84 on bridge above Fishkill Hook Road; Cambro-Ordovician carbonates dipping SE on NW limb of syncline.
[46.7] White Proterozoic in cuts.
[47.3] Outcrop S of hill: Poughquag Quartzite (?); I-84 curves R.
[47.9] Passing sign advising upcoming Exit 13, US Route 9; I-84 on bridge above Gary Road. Cuts expose Proterozoic metamorphic rocks. Hudson Highlands on L (south).
[48.5] Proterozoic on R.
[48.9] Leaving Hopewell Junction quadrangle; entering Wappinger Falls quadrangle.
[49.0] Exit I-84 at ramp on R.
[49.2] Enter US Route 9, northbound.
[49.8] Crossing bridge over Fishkill Creek.
[49.9] Crossing RR tracks; entering Fishkill.
[50.9] Jct. of old Route 9 and new Route 9: Proterozoic rocks (JES thinks probably from a central-shelf overthrust) exposed in roadcuts on E side; in Fishkill.
[53.4] Traffic light; Dutchess Co. Route 28.
[53.3] Just S of RJ Route 9 and Co. 28: M. Ord. slates of Tippecanoe Sequence.
[53.4] Traffic light; Dutchess Co. Route 28.
[53.5] More cuts of Tippecanoe Sequence slates; also present here are interbeds of thin graywackes showing low dips.
[54.1] Traffic light; Dutchess Co. Route 93; move left for upcoming left turn.
[54.7] Where US Route 9 curves to R at light opposite Dutchess Shopping Plaza on R and just before Dairy Queen on L, turn to L for East Main Street, Route 9D, to center of Wappingers Falls.
[55.1] Turn R for Mesier Park, then R again in front of Police Station; continue to spaces for public parking for Stop 5.

STOP 5 - Tippecanoe Sequence: black shale and interbedded graywacke in Mesier Park, Route 9D, Wappingers Falls, New York. [UTM Coordinates: 590.17E / 4605.48N, Wappingers Falls quadrangle.]

This will be a brief stop at a convenient place for viewing the weathered massive graywacke layers in the Tippecanoe Sequence (M. Ord.). Graywackes are typically dense, highly indurated, gray to greenish-gray, poorly-sorted, heterogeneous sandstones containing an abundance of angular to sub-rounded grains of quartz, feldspar, lithic fragments (including limestone, slate, phyllite, chert, and/or volcanic fragments). If the volcanic component is high they are refered to as volcaniclastic graywackes. Graywackes are commonly deposited episodically during turbidity flow from shallow- to deep-water depositional environments. As such, they represent displaced sequences which harbor interesting primary sedimentary structures that are products of their episodic flow and emplacement.

Here, the graywackes form highly jointed, massive outcrops with approximately north-south strikes and steep easterly to vertical dips. Sedimentary structures include local shaly interbeds, large-scale cross beds, rolling ripple laminae, and amalgamated ripple bedding. These rocks were deposited in the foreland basin that replaced the shallow-water carbonate shelf on which the Sauk Sequence was deposited. They are structurally overlain by allochthonous rocks of the Taconic sequence.

[55.3] Reboard vans and drive to end of driveway, turn R; turn R again at traffic light for US 9D.
[55.5] Park on bridge over Wappinger Creek for Stop 6.

STOP 6 - Tippecanoe Sequence: black shale and interbedded graywacke exposed in Wappinger Creek, beneath bridge on Route 9D, Wappingers Falls, New York. [UTM Coordinates: 589.94E / 4605.67N, Wappingers Falls quadrangle.]

Again, just a short stop (time permitting) to look over the edge of the bridge and examine graywackes differentially eroded by Wappinger Creek. Here, the creek has deeply eroded the shaly interbeds and the massive graywackes form prominent outcrops in the creek bed. Note the potholes formed by swirling waters. With a strike essentially parallel to the south-flowing creek, these beds are oriented steeply eastward to vertical in dip and control the orientation of Wappinger Creek. Also note the building stones used along the bridge. These are potassium feldspar-rich sandstones (arkose) probably from the Newark Basin.

[55.5] Continue on US Route 9D.
[56.7] Traffic light at entrance to South Hills Mall; turn R and then L to park in lot by small shopping center across the street from the Taj Mahal Restaurant for Stop 7.

STOP 7 - Sauk Sequence: Pine Plains Formation (Upper Cambrian), Wappinger Group, at entrance to South Hills Mall. [UTM Coordinates: 590.16E / 4607.52N, Wappingers Falls quadrangle.]

The roadcuts directly north of the parking lot opposite the entrance to the mall expose thick bedded hummocky dolostones showing alternating A-B-A-B lithologic layering. Here, as in Stops 2 and 4, the light-colored layers were originally massive, coarse-textured carbonate sands and the darker layers are finely laminated carbonate muds. Stylolites are developed in two directions, one set parallel to bedding (often with branching forms) and the other set at a high angle to bedding. The presence of the secondary high-angle set is evidence that layer-parallel shortening here was greater than in the exposures of these carbonates we have seen previously.

Structurally, the rocks of this stop dip beneath the graywackes exposed at Mesier Park and Wappinger Falls thus forming the northern limb of a syncline. Of further geological interest here, note the diagenetic bedding (dark streaks), burrow mottles resulting from bioturbation of soft sediment by burrowing creatures, micro-geodes filled with carbonate, and high-angle brittle faults. In addition, around the north-facing end of the exposure note the high-angle normal fault dropping the laminated darker dolostone (B) against the massive light-colored dolostone (A).

[56.8] Reboard van; leave parking lot, turn R, then R again at the traffic light, but move into L lane for L turn at next light, junction US Route 9.
[56.9] Jct. of Route 9D and Co. 77 with Route 9; turn L at light to enter US Route 9, northbound. [On the E side of Route 9, Co. 77 becomes Vassar Rd.] On the W side of US Route 9, opposite the Burger King on the NE corner of this intersection, the cuts expose more carbonate rocks of the Sauk Sequence.

[57.0] Opposite Cines 8 and South Hills Mall, and the next driveway N from Mr.Bagel, pass entrance on R to Dorchester Arms Motel on R. ["We shall return."] Mrs. Yang (914) 297-3757; $37 single; $44 double. On W side of US 9, directly opposite the motel, a construction project in progress is making new exposures of Sauk Sequence carbonates.
[57.1] Traffic light for local streets.
[57.2] Just ahead on R is Dutchess Diner (open 24 hr.)
[57.3] Sauk carbonates in roadcut opp. mall entrance.
[57.4] More Sauk carbonates; steep dip to NE.
[57.6] Traffic light at Spring Rd.
[57.7] Sauk carbonates exposed in cuts on both sides of US Route 9; on L, large boudins here.
[57.8] More Sauk carbonates exposed both sides; much deformed.
[57.9] More Sauk carbonates on both sides; then no more rocks exposed in cuts.
[58.3] Ramada Inn on R.
[59.0] Traffic light at entrance on R to IBM Country Club.
[59.2] Roadcut on R exposes low-dipping Sauk carbonates, opposite Red Bull Motor Lodge.
[59.3] Kingwood Park; Co. Route 48 on L to IBM plant.
[59.6] Spackenkill Road; nearly horizontal carbonates of Sauk Sequence. The most-recent written "pronouncement" on these carbonates is contained in an article by Fisher and Warthin

(1976). These two students of the local rocks showed "tentative structural sections" on which they indicated faults of four different ages: from youngest to oldest:

4. "Triassic (Palisadian) normal faults."
3. "Devonian (Acadian) reverse faults."
2. "Ordovician (Taconian) thrust & reverse faults."
1. "Ordovician (Taconian) thrust faults, associated with gravity slides."

JES thinks this list is deficient in at least two respects (it lacks any Late Paleozoic faults, the Appalachian, downgraded by many into the "Alleghanian") and it perpetuates the "gravity-slide" buzz word for the great Taconian displacement that moved across the sea floor in what was a former upslope direction. CM does not believe in gravity sliding either but argues (see Stop 8) that all Taconic displacements were driven by subduction-related thrusting of the allochthons and underlying continental- margin sequence. Secondly, the Fisher and Warthin fault sequence lacks any but sparing identification of post-Newark faults (now known to have been of mid-Jurassic age, not Triassic, and probably best not designated by the term "Palisadian," but that is a whole other debate in itself).

Since 1963, JES has maintained that the post-Newark deformation involves several stages of faulting, including strike-slip faults; that the displacements on these faults were very large (thousands of meters); and that the displacements extended into the older rocks (where their ages based on the ages of rocks offset cannot be proved by traditional geologic methods; i.e., Proterozoic rocks faulted against Paleozoic rocks imply faults that are only younger than the youngest rocks cut). The existence of "late," steep, brittle faults having large displace-ments has been proved by continuous seismic profiles (G. M. Friedman, personal communication to JES). JES would interpret many of the contacts Fisher and Warthin mapped as "megabreccia slide contacts" on their generalized geologic map (Figure 25) (but do not show on their structure sections) as mid-Jurassic steep faults.

[60.3] Traffic light; Poughkeepsie Plaza Mall on R; Hudson Plaza on L.
[60.9] On W side of Route 9: home of Samuel F. B. Morse (inventor of telegraph; name honored in "Morse code").
[61.3] Traffic light at Sharon Dr.; passing Holiday Inn Express on R; and cemetery on W side of Route 9.
[61.4] Passing sign on R for upcoming exit to Academy St.
[61.5] Cuts on R expose M. Ord. slate and graywackes of Tippecanoe Sequence.
[61.7] Passing ramp on R for Academy St.
[62.2] Passing ramp on R for Fox St. and Prospect St.
[62.6] Leave US Route 9 by exiting to R into ramp for Rinaldi Blvd. and Columbia St.
[62.65] At end of ramp, turn L and cross over US Route 9.
[62.7] Turn R and proceed downhill to stop sign at Columbia Street; after stop, turn L, following sign for Rinaldi Blvd.
[62.8] Pass under Amtrak RR; at end of underpass, jct. of Columbia St. and divided-lane Rinaldi Blvd.; turn R onto Rinaldi Blvd.

[63.0] Sign for Truck Route and Laurel St. on R; turn L. into Gerald Drive directly opposite Laurel St.
[63.1] Passing Stout Dr. on L.
[63.3] Turn L on Hendryk Dr. and drive downhill to Kaal Park.
[63.5] Park in parking lot, Kaal Park, under mid-Hudson Bidge.

STOP 8 - Poughkeepsie Olistostrome(?) or Mélange(?) Unit, Kaal Park, under the east footing of the Mid-Hudson Bridge. [UTM Coordinates: 588.00E / 4617.15N, Poughkeepsie quadrangle.]

One of the perplexing problems facing geologists in studying rocks associated with subduction zones, forearc and backarc basins, and in this case, arc-continent collisional orogens, is the identification of pre-tectonic soft-sedimentary slump deposits (called olistostromes) from tectonically deformed packages of incipiently lithified sediment (mélange) formed penecontemporaneous with the emplacement of thrust sheets. Here, in spectacular poison-ivy-covered exposures beneath the bridge, we will attempt to make observations and discuss this problem in order to decide, in a living laboratory - "Well Mabel, is it sedimentary, tectonic, or a combination of the two?". Because of the fact that your trip leaders are in partial disagreement over this matter, with JES supporting a soft-sediment slump model (naturally) and CM (of course) supporting the tectonic model, perhaps your observations can settle this once and for all without the need for fisticuffs, late in the day, on raw rock, in the poison ivy.

First, a little background information on the controversy, which developed even before the advent of plate-tectonic hypotheses involving the sedimentology and tectonics of formerly active accretionary complexes (subduction zones). According to, and paraphrased from, the AGI Glossary of Geology, in the current usage, a **mélange** is a heterogeneous, mappable body of deformed rocks consisting of a pervasively sheared, fine-grained, typically pelitic matrix which is thoroughly mixed with angular and poorly sorted inclusions of native- and exotic tectonic fragments, blocks, or slabs (of diverse origins and geologic ages), that may be as much as several kilometers in length in a deformed and sheared matrix. Also according to the AGI Glossary, an olistostrome is a sedimentary deposit consisting of a chaotic mass of intimately mixed heterogeneous materials (such as blocks and mud) that accumulated as a semifluid body by submarine gravity sliding or slumping of unconsolidated sediments. It is a mappable, lens-like stratigraphic unit lacking true bedding but occurs intercalated among normally bedded sequences. Thus, mélanges are tectono-stratigraphic units, not lithostratigraphic units.

In 1919, Greenley introduced the term mélange to describe the Mona Complex of the Guna mélange in Anglesy, Wales. The term was little used until Bailey and McCallien (1950) resurrected it. Wood (1974) showed that Greenley's original type locality was actually a sheared olistostrome, further confusing geoscientists. Hsu (1968, 1974) redefined mélange (to our current usage) and established some guidelines for distinguishing them. We refer you to a GSA Special Paper edited by Raymond (1984) on the classification of mélanges.

All geologists concede that mélanges and olistostromes are difficult to tell apart in a single exposure, especially if post-emplacement deformation has occurred! That is, olistostromes can be deformed after slumping and thus can be misidentified. Such confusion will lead to gross tectonic mistakes when paleo-reconstructions are attempted, as important differences between the two exist. Some of the rules applied to identification in the field and application for tectonic reconstructions as presented by Hsu (1968, 1974) are outlined below to help you take sides in the "Great Debate at Kaal Park":

Rule 1 - A mélange can be brittle or ductile and is formed from lithified chaos whereas an olistostrome consists of pre-lithification chaos.

Rule 2 - Olistostromes are generally less that a hundred meters thick and bounded by sedimentary units; mélanges are often up to 10 kilometers thick (debatable!).

Rule 3 - Although tectonic rounding may occur, most brittle mélange blocks are bounded by fracture surfaces. Ductile mélanges (or transposition mélanges) contain rootless structures and isoclinal folds, and,

Rule 4 - Obey all rules.

Now that we are all thoroughly confused let's try to make some observations, on the rocks (to coin a phrase!), to help us get beyond the stage of arm waving and into finger pointing. The rocks exposed on the cliff face consist of poorly sorted, variably oriented, angular- to rounded chaotic blocks of graywacke and quartzite in a sheared, unbedded shaly to slaty matrix. Fisher and Warthin (1976; Stop 6 NYSGA Trip) argue that this unit is "an exquisite exposure of a tectono-sedimentary unit known as chaos, mélange, olistostrome, or wildflysch". Nothing like covering all the possibilities! Fisher (1976, in press) has named the unit the Poughkeepsie Mélange. He states that elsewhere the unit contains blocks of quartzite, sandstone, shale, and carbonate (but does not state whether they are Taconic carbonates or Wappinger Group!) and suggests that the " mélange " is a soft-sediment slump called the Livingston Slide. How confused are you now? Are you as confused as Fisher? As lost as Jimmy Hoffa? As confused as CM and JES? We hope not! Let's turn to the videotape (exposure). Let's collect the facts as we see them.

Fact 1 - The rocks are indeed black argillite in which numerous blocks of quartzose arenite in variable orientation exist. The arenite blocks range from cobble- to boulder size, show internal grading (tops indicators), laminated upper portions, and glazed bottoms (a result of sedimentary loading). The blocks are surrounded by a shaly- to slaty black matrix. In addition, larger, 2-3 m thick, internally bedded masses are surrounded by shaly- to slaty sheared margins and found rotated into various attitudes. The interbeds of arenite are separated by the same black shale (slate?) found elsewhere in the exposure. Taken together, we see what most geologists would argue is a "broken formation". But a broken formation of what? Interbedded shales and arenites which could be none other than the Tippecanoe Sequence (Middle Ordovician) flysch part of the filling of the foreland basin (great exposures to be seen at Stop 9 (tomorrow morning)). By contrast, Fisher, and others, say these rocks belong in the Taconic Sequence and are related to a subduction zone.

Fact 2 - The unit is strongly deformed; the outlines of the arenite blocks are rounded to angular. Typically, arenite masses are flattened parallel to the sub-horizontal slaty cleavage which forms a crude clast shape-fabric to the outcrop.

Fact 3 - Many of the blocks are elliptical in shape showing flattening in the subhorizontal dimension and linear elongation (within the plane of flattening) toward the east.

Fact 4 - The slaty- to shaly matrix anastomoses around the blocks of arenite (not through them) and the outlines of the blocks are sharp, not wispy or gradational.

In the light of these facts, CM argues (without significant hesitation) that the unit represents a ductile tectonic mélange but leaves open the possibility that limited internal soft-sediment deformation in the autochthon preceded the effects of low-angle thrusting. CM argues that the dominantly pelitic matrix, monomict clast population, pervasive shearing of the matrix, and sharp clast outlines all argue for a ductile mélange call on this one (JES note: based on the rules outlined by CM!). CM views the overall crude shape fabric and rounding of the clasts as tectonic in nature and the strong alignment of elliptical clasts vectorally pointing toward the direction of overthrusting. In most thrust zones, strong down-dip alignment of linear elements is taken to indicate the tectonic-transport direction, an observation that would certainly "fit the model" of Taconian continentward advancement of allochthons here, or, for that matter, post-Taconic low-angle faulting. The lack of soft, wispy outlines, the lack of injection of mud into the "non-lithified" arenite blocks, and the lack of polymict clasts argue against a pure olistostrome model for the exposure in his view. CM is not opposed to the concept of early, limited soft-sediment deformation but would tend to interpret this exposure the result of incipient subduction of the medial Ordovician foreland basin beneath the advancing active overthrust toe of the Taconic subduction complex. Implicit in this idea is that the foreland basin fill (the Tippecanoe Sequence, here) was dragged down into the trench for hundreds of meters or more, with mélange formation and subsequent shearing related to subduction. As these rocks are considered part of the autochthon, they may have been involved in incipient subduction during the final stages of Taconian arc-continental margin convergence! Deformation of the Poughkeepsie Mélange may also be the result of post-Taconic (post Medial Ordovician = Acadian or Appalachian) low-angle faulting or shearing.

JES points out that the terms used by Fisher and Warthin are not synonymous, and that clarity will be improved by using them as originally defined. Fisher has expressed his interpretation by applying "mélange" as a formational designation. But a mélange is not the same thing as an olistostrome, a wildflysch, or a chaos, which are clearly products of subaqueous, gravity-driven "mass-wasting" activities. JES argues that exposed here is an olistostrome because "blocks" are the shallow-water type and argues that the arenites (now quartzites) are possibly topset beds of a delta. He views the imbrication of the blocks as being a result of gravity slippage which caused them to become bent before cementation. According to JES, the pieces of the arenites moved downslope to deeper water where pelites were being deposited as the large slabs are parallel to the depositional surface (i.e. - bedding). JES suggests that the pieces are too small to have been pried loose by an overriding overthrust sheet and that deep burial and deformation occurred later, resulting in the cleavage. CM asserts that JES may have slumped on this interpretation! What do you think? Can they both be right? Of course! -- This is the appeal of academia.

Remarks about the "mélange," as seen when leaves are absent.

1. The only kind of material forming the blocks is coarse quartzose arenite (quartzite? as contrasted with Austin Glen graywacke). Discrete bits and pieces of arenite are scattered at random everywhere within the cleaved black-shale matrix, in all possible orientations. Some clearly show sole marks that indicate original bottoms. Some that have been folded are completely upside down. At N end, the large continuous layers may be part of an isoclinal anticline, with tops both directions away from the shale in the middle.

2. What age are the disrupted arenites? To JES they look most like the so-called Quissaic Quartzite, DWF's Upper Ordovician molasse present on W side of Hudson River. An age as late as Late Ordovician for the disrupted arenite would scuttle the DWF idea of a Taconic mélange here. Is Quissaic the top of the Austin Glen (poss. Ramseyburg member of Martinsburg) or even younger than the upper shale member (=Penn Argyl member)? If so, then syndepositional faulting in the foreland basin during deposition of the Penn Argyl member could be an explanation for simultaneous deposition of the matrix here and the disruption of the arenite. This assignment eliminates any "Normanskill" age even if one accepts the Late Trentonian assignment of Ruedemann and WNB Berry).

If the breaking of the arenites is not syndepositional but is tectonic, then when was the deformation and tectonic mixing? Acadian? CM suggests that is possible. Or even Appalachian? Both would be in a backarc setting, not within the main subduction zone. Similar relationships are described by Vollmer and Bosworth (1984) for other localities west of the Taconic range.

JES afterthought: what about this as one of the Queenston deltas? The big news on "deep-water" (> 20 m) modern deltas from the NW Gulf of Mexico is that the sand brought to the ends of the distributary channels during floods founders into the thick hydroplastic muds (the H. N. Fisk "bar-finger sands") and all manner of slumping takes place even on very low slopes. The fact that no other kinds of coarse arenites are present or other kinds of rocks (carbonates, granites, etc. - despite Fisher's pronouncement on a variety of blocks) is consistent with a deltaic interpretation. Also, the matrix interbedded with arenites in large, multi-bed masses is the same as the general matrix (the suspended load of the river?). This delta idea needs checking. If correct, it completely revises the interpretation here and the tectonic significance of the old Poughkeepsie Mélange goes slumping into the scrap heap.

[63.5] Leaving Kaal Park parking lot.
[63.6] Stop sign at top of hill; turn R. on Gerald Drive.
[63.7] Passing Stout Court on R.
[63.75] Jct. of Gerald Dr. and Rinaldi Blvd; turn R on Rinaldi Blvd; RR tracks on L;
[64.0] Dead end, cor. Rinaldi Blvd. and Columbia St.; turn L onto Columbia St. and go under Amtrak RR heading E.
[64.1] Turn R and go uphill on not-marked street; continue ahead onto merge ramp for southbound US Route 9.

[64.2] Merge with US Route 9 southbound; sign announcing Fox St. and Prospect St. 1/4 mi. ahead.
[64.4] US Route 9 curving L; passing ramp on R to Fox St. and Prospect St. US Route 9 is on a bridge over local streets.
[64.8] Passing exit ramp on R for Academy St. and South Ave.
[68.6] Move L to be in left-turn lane at traffic light at S. end of South Hills Mall; jct. Co. 77 (Vassar Rd. on E side of US 9) and Route 9D. Make U turn for northbound US Route 9.
[68.7] Turn R into driveway for Dorchester Arms Motel. This is our home away from home for tonight. Register. Make dinner plans.

END OF FIELD TRIP DESCRIPTION - DAY ONE

BEGIN FIELD TRIP DESCRIPTION- DAY TWO

[0.0] Turn R out of motel driveway onto northbound US Route 9.
[0.1] Traffic light for local streets.
[0.3] Turn R for Dutchess Diner (open 24 hr.) Breakfast stop.

[0.3] After breakfast, leave diner; turn R for northbound US Route 9. Repeat segment of log from Day 1, mileage 57.2 to 62.6.

[5.1] Passing exit ramp on R into ramp for Rinaldi Blvd. and Columbia St. (where we turned off yesterday). Move left into center lane for upcoming exit to left.
[5.8] Make sharp U turn to the L for NY 55, US Route 44 westbound and the Mid-Hudson Bridge.
[6.0] Enter ramp leading to Mid-Hudson Bridge.
[6.1] On Mid-Hudson Bridge. Passing deep cuts in Tippecanoe Sequence (Middle Ordovician) graywackes. According to Fisher and Warthin: "Rocks of the Livingston Slide are superbly exposed at the western end of the Mid-Hudson Bridge." And: "the Livingston and Van Buren Gravity Slides were emplaced into the Magog (Snake Hill-Martinsburg) Trough" ... "during the Vermontian Phase of the Taconic Orogeny (mid-Mohawkian time)."

[6.1]   Toll plaza, Mid-Hudson Bridge; a freebee going W.
[7.6]   Turn R on US 9W in directon of Highland, New York.
[8.2]   Turn R onto Haviland Road to Johnson Iorio Park.
[9.2]   At end of road, park for Stop 9.

STOP 9 - Tippecanoe Sequence: flysch of foreland-basin filling, west footing of Mid-Hudson Bridge, NY Route 44 (old and new) and Johnson Iorio Town Park, Highland, New York. [UTM Coordinates: 587.11E / 4617.22N, Poughkeepsie quadrangle.]

As a preface to this morning's first stop and in order to set a proper backdrop for the observations to be made here, we urge you to read the introductory discussion of the Taconic

Problem. The rocks magnificently exposed on the west end of the Mid-Hudson Bridge are part of the Tippecanoe Sequence (Middle Ordovician) flysch deposits, the bulk of the filling of the foreland basin that supplanted the carbonate shelf when the passive-margin plate setting became convergent.

The new location of US Route 44 going west from the Mid-Hudson bridge has involved making splendid deep cuts through the coarser member of the Middle Ordovician flysch (possibly the Ramseyburg Member of the Martinsburg Formation, but use of that name here is not a matter of general agreement; others would opt for Austin Glen). We plan to spend much of our time in the cuts along the former location of Route 44, now a town park and thus not subject to the problems of fast-moving vehicles and anxious Bridge Authority patrols, who seem determined to keep geologists from looking at these splendid strata. We may try to look at the new cuts on the N side of the new location of US Route 44; to do so we shall park along the old Route 44 and climb up a hill to the new cuts.

Are these "Normanskill"? If so, what is the "Normanskill?" If it is what Ruedemann (1901) originally thought it was, then it is entirely younger than the carbonates and thus part of the foreland-basin filling. [The foreland basin formed after the carbonate shelf underlain by the Sauk Sequence dolostones had been subaerially eroded, and later re-submerged and the basal limestones of the Tippecanoe Sequence (=Balmville Limestone) accumulated.] If one goes by the old Ulrich-Riva-Fisher view (which both JES and CM think is totally wrong), then the Normanskill is Chazyan and has to be part of the Taconic Sequence, thus part of the great overthrust (or gravity slides, according to Fisher and Warthin). The original Taconic succession has been reinterpreted as a deposit of an ancient continental rise along which contour currents were active (B. D. Keith and Friedman, 1977).

Not long after the kinds of sedimentary structures found in the Alpine flysch were published, several workers found comparable features in the Martinsburg Formation in the central Appalachians (van Houten, l957; McBride, 1962). Other studies made of these Hudson Valley graywackes using the concept of turbidity currents included preliminary analysis of paleocurrents (Middleton, 1965); size and sphericity of quartz (Middleton, 1962); and particle fabric (Onions and Middleton, 1968). In addition, a detailed sedimentologic study of the Cloridorme Formation, a Northern Appalachian Ordovician flysch well exposed along the south shore of the St. Lawrence River in Quebec, was made by Enos (1969a, 1969b), who found compelling evidence for the simultaneous transport of the sand- and mud-size fractions. Enos thus demonstrated that much of what should be considered as turbidite consisted of the fine sediment, in contrast to the coarser debris usually considered to be the characteristic deposits of turbidity currents.

One of our objectives will be to see if we can find any evidence at Highland, New York, that bears on the question of what sediment should be classified as turbidite.

The strata here include many of the kinds of primary sedimentary structures that JES used as the basis for his argument about what are and what are not turbidites and for the analysis of convoluted laminae as products of simultaneous deposition and deformation as the bed builds upward and of differential deposition of very fine sand and the silt/clay fraction along the crests and troughs of climbing ripples ("ripple drift with deposition from above" of H. C. Sorby).

One of the points JES has tried to make in analyzing gravity re-sedimented deposits is that many of the coarse strata of flysch sequences (notably the A division of the Bouma turbidite sequence) are not in fact turbidites, but were emplaced by the action of liquified cohesionless coarse-particle flows that moved along the bottom, possibly beneath a true turbidity current. The crux of the JES argument is that true turbidities are characterized by features made when sand is deposited out of turbulent suspension while the current, which by definition is flowing because of its load of suspended sediment, is still moving. When any current carrying sand in suspension slows down and begins to deposit the sand within the range of speeds where ripples form in fine sands (we would refer to this as being in the lower flow regime today), it deposits climbing ripples and their characteristic ripple-drift cross laminae. The important characteristics of ripple-drift cross laminae is that the forward motion of the ripples, which is a function of the current speed, and the rate of sand fallout from suspension determine the angle of "climb" of the line joining the crests of the successive ripples.

Climbing-ripple laminae were first described in the American literature from glacial outwash (J. B. Woodworth, 1901). Since then, they have been mentioned from the deposits of the flood plain of the Colorado River in the Grand Canyon (E. D. McKee, 1938), and elsewhere. Sanders discussed them briefly in a paper on the mechanics of deposition (Sanders, 1963) in the same year that Roger Walker (1963) analyzed them as related to turbidity currents. Since 1963, many papers have appeared in association with turbidites and with glacial outwash (R. G. Walker, 1969; J. R. L. Allen, 1970, 1971a, 1971b, 1973; Jopling and Walker, 1968, to list a few examples).

Based on the analysis of Mutti (1974), we think it is appropriate to classify the strata here as being deposits of the outer parts of former basin-floor fans. The predominant facies consists of fine-textured, brown-weathering, thin sandstones and interbedded mudstones. Within this predominant bipartite facies are units of dark bluish-gray, coarser graded graywackes. According to the JES interpretation, the fine-textured, brown-weathering, thinner sandstones, which contain abundant tractional laminae, are true turbidites. By contrast, JES regards the coarser graywackes, which generally lack tractional structures as not being turbidites. The following paragraphs contrast the features within these two groups of strata.

Current-caused features of the fine-textured, brown-weathering sandstones.

The fine-grained, brown-weathering sandstones display a complete set of primary structures formed by deposition of fine sand from currents moving fast enough to create "normal" ripples, to cause these ripples to migrate downcurrent, and in some instances, to cause the ripple laminae to be oversteepened, even overturned, and convoluted. Examples can be found of climbing ripple-drift ripples, of climbing partial-drift ripples, of climbing oversteepened ripples, and of climbing sets of convoluted laminae (Figure 27).

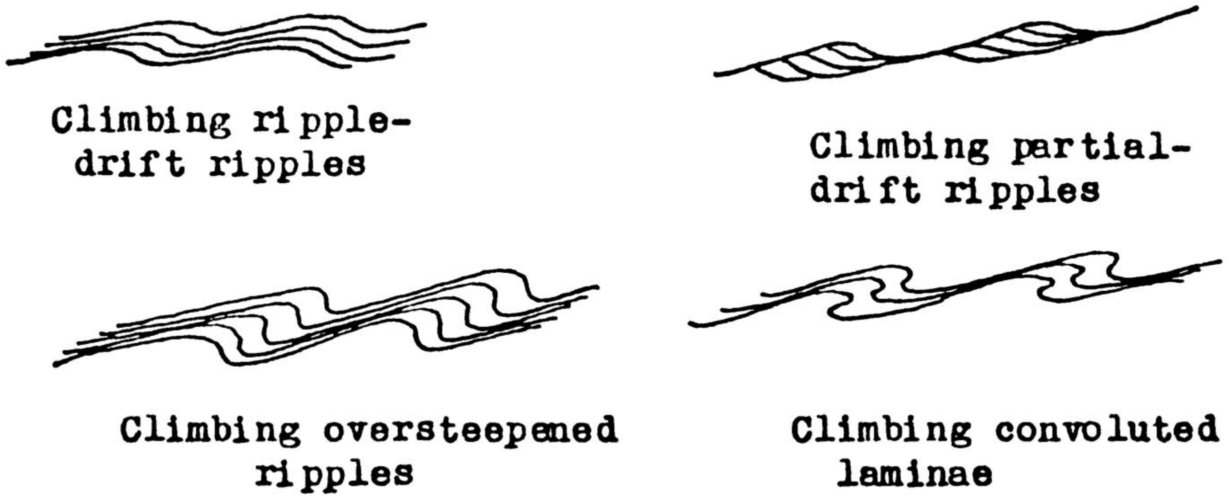


Figure 27 - Transition from climbing ripples (ripple drift) to climbing convoluted laminae. All stages are present at Stop 9. Drawing by J. E. Sanders.

Other examples display the effects of what have been referred to as foundered (or "load-casted") ripples (Dzulynski and Kotlarczyk, 1962). JES is not persuaded of the validity of the concept of "load-casted" ripples. Rather, he prefers the concept that the deformed cross laminae were deposited in the lee of a growing mud wisp, with a resulting pattern of deformation and deposition that typifies convoluted laminae where the upgrowing parts of the bottom consists of a ripple crest instead of a pointed mud wisp being deformed (Figure 28).

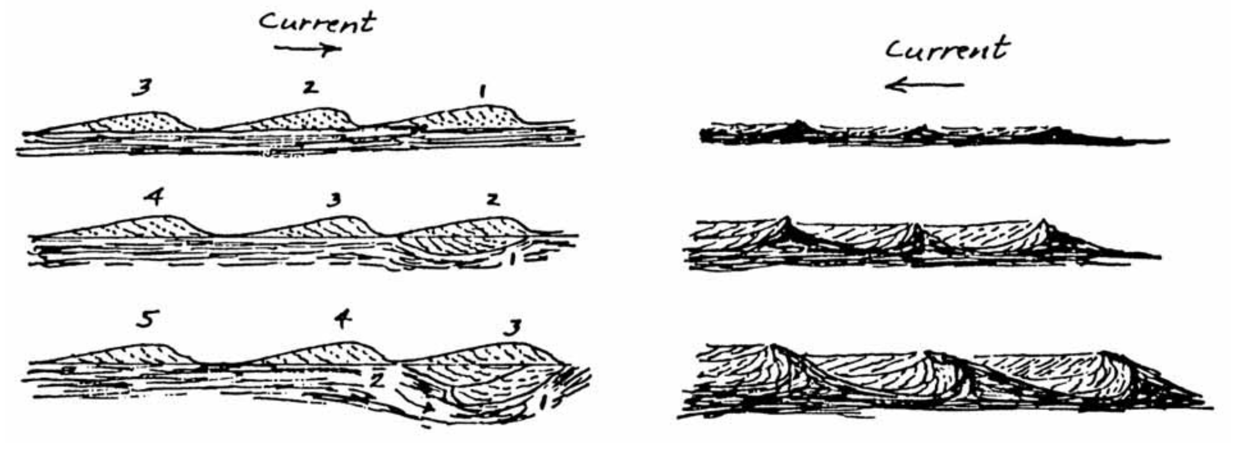


Figure 28 - Comparison between "load-casted" ripples (left) and cross-laminated sand deposited in lee of upgrowing mud wisp. "Load-casted" ripples from Dzulynski and Kotlarczyk (1962, Fig. 3, p. 149; growing mud wisps from Sanders, 1965, Fig. 1, p. 198, but redrawn and slightly modified). Under the ripple-foundering process, the weight of a ripple starts flowage, and flowage continues as more ripples reach the sinking spot. Under the growing-wisp process, sand is deposited in the lee of the raised wisp to build up a smooth bottom. As further deformation takes place from current shear, the cross-laminated sand becomes deformed and may even be overturned, but eventually, as the current wanes, the dip of cross laminae becomes "normal" and the bed becomes smooth. These same kinds of deformed lee-side cross laminae are found in convoluted laminae where the mud wisps in the sketch above are replaced by fine sand displaying oversteepened ripple laminae. Drawing by J. E. Sanders.

Where ripples were forming from a supply of sediment consisting of both fine sand and coarse silt, the shapes of the growing ripples evidently influenced the sorting. In some examples, the brown-weathering fine sand was concentrated at the ripple crests, whereas the dark-colored coarse silt accumulated in the ripple troughs. As the ripples grew forward and upward, a small-scale interfingering of these two kinds of sediment was built into the beds (Figure 29).

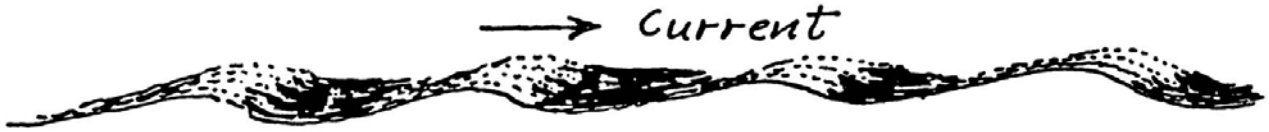


Figure 29 - Incomplete sand-mud ripples. Brown-weathering fine sand, not present in quantities sufficient to cover the whole ripple, is concentrated at ripple crests. Dark-colored silt fills ripple troughs. Drawing by J. E. Sanders.

JES infers that this interfingering of fine sand and silt shown by the ripples proves that the brownish-weathering fine sand and dark gray silt were being deposited by one and the same current at one and the same time and thus, that the silt is every bit as much as a turbidite as is the fine sand. If one accepts this conclusion, then it follows that the differentiation of the sediment into beds of "coarser" sandstones and "finer" siltstones is a function of current action. Moreover, it would be erroneous to consider that the "fines" in this case represent pelagic sediments that were deposited between turbidity currents. In this cut, pelagic sediments are rare. You might find it instructive to search for examples of what you would consider to be valid pelagic sediments.

Features within the coarse graywackes

In general, the coarse graywacke beds display few internal sedimentary structures. Along the basis of many, one can see evidence that the newly deposited coarse sediment foundered into what must have been a hydroplastic (Shrock, 1948) substratum. The resulting features (named "load pockets" by Sullwold, 1959) usually contain sediment that is coarser then the sediment found along the bottom of the same bed away from the pocket (Sanders, 1965, p. 209-211; Fig. 3, p. 210).

CHECK LIST OF TOPICS FOR ADDITIONAL DETAILED STUDY

Style of sedimentation

What are the turbidites?
What are pelagic sediments (if any)?
Do any patterns exist: Among sizes of particles? Within individual beds? Within sequences of beds? With respect to thickness of beds?

Features on bottoms of beds: Evidence of reaction between cohesive substrate and current that emplaced the sand-size sediment (products of depositing-deforming currents, such as "flame structures").
Scour marks vs. tool marks vs. bioturbate structures.

Evidence of erosional truncation.
Compare kinds of marks with kind of overlying bed (as did Pett and Walker, 1971, for example).
Features within beds: Any laminae? Give details on thickness, plus size variation.
Ripple laminae? Climbing ripples? Any truncation?
Have foresets been oversteepened? Do sand layers extend across the ripples?
Convoluted laminae (look for evidence of progressive deformation while current was depositing sand). Any "climbing convolute anticlines"? Pelitic intraclasts?

Features on tops of beds: Nature of contact (sharp vs. gradational). Ripples? (Note orientation). Be on the lookout for patterns in the vertical succession.

[9.2] Retrace route to US Route 9W.
[10.2] Turn L at light, enter US Route 9W, southbound.
[10.4] Enter ramp on R for Mid-Hudson Bridge.
[11.1] Toll plaza. Pay up. Drive East. Continue E on US Route 44 and NY 55
[15.0] Turn R on NY 55.
[17.1] Turn R on Dutchess Co. Route 21.
[21.0] Deep cuts, both sides of Noxon Road.
[21.7] More deep cuts and this is Stop 10.

STOP 10a - Taconic Sequence/Tippecanoe Sequence contact: The Taconic thrust (?) or post-thrust normal fault (?), Duchess County Road 21, Noxon, New York. [UTM Coordinates: 599.41E / 4610.87N, Pleasant Valley quadrangle.]

This exposure was described by Fisher and Warthin (1976; Stop 3 NYSGA Trip) and Bence and McLelland (1976; Stop 1 NYSGA Trip) and we borrow from their discussion but differ from their interpretation. They describe the Mt. Merino Shale on the west and the Indian River Shale on the east and correlate them with the middle and lower divisions of the Normanskill Group, respectively. F & W say the gray shales are the Mount Merino, thus part of the Taconic sequence (in their BS about the Normansksill being Chazyan). If the dark stuff is post-carbonates, then it is in situ as far as the Taconic displacement is concerned, and the Taconic rocks in the E end of this cut are faulted against the dark shales. The fault could be a "late" brittle, normal fault (JES leans toward Jurassic).

Bence and McLelland comment: The contact between the two contrasting rocks is "just at the western end of the red Indian River exposures. Some faulting appears to have occurred along the contact and a later northwestward dipping (sic) reverse fault, with associated fracture cleavage, further complicates relationships." (1976, p. B-7-20). (Fisher and Warthin's remark on p. B-6-22 tells all: No fossils here, but "elsewhere, where less deformed, the Indian River and Mt. Merino yield graptolites characteristic of the Nemagraptus gracilis zone of the Early Medial Ordovician." Give him an A for the "medial" and the "early" for the time reference, but flunk him on everthing else).

CM and JES point out that the rocks in the exposure in front of you are not fossiliferous. Thus their age assignment is based on far-reaching lithostratigraphic correlation where key graptolites from the Nemagraptus gracilis zone occur in less-deformed strata. Both CM and JES have difficulty with the Fisher and Warthin scheme as described below.

Firstly, the rocks exposed in the large roadcuts are slates (metamorphic rocks) not shales as reported by Fisher and Warthin. We here argue that the eastern end of the exposure consists of variegated slates of the Taconic Sequence (thus, part of the Taconic allochthon) but that based largely on physical stratigraphic grounds, the western part, indeed, consists of black slates of the Tippecanoe Sequence (which also includes such formations as the Martinsburg, Normanskill, and Walloomsac). If we are correct, then within these roadcuts is a major tectonic boundary between the two so-called "pelitic" sequences! One possibility is that the tectonic boundary is none other than the Taconic overthrust itself. Figure 30 is a schematic cross section showing this interpretation. Another possibility is that the Taconic overthrust, a low-angle feature except at its very "snout," lies hidden below the level of the road and that the boundary between the two Sequences at the level of the roadcut is a post-thrust normal fault (with E side relatively downdropped). Check any slickensides present to ascertain direction of last fault motion.

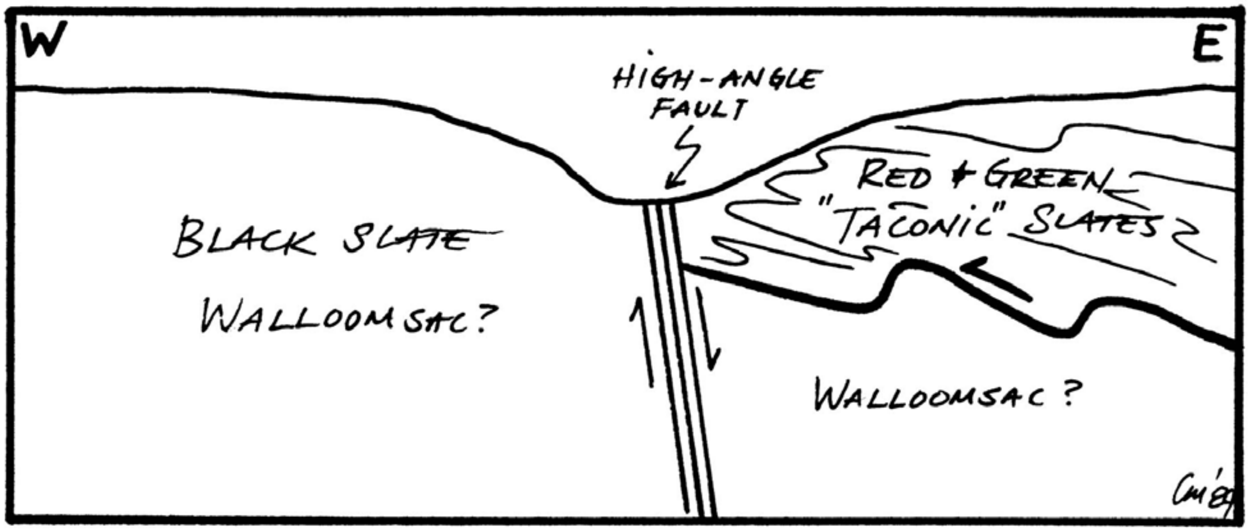


Figure 30 - Diagrammatic geologic interpretation of Taconic thrust contact exposed at Stop 10.

Starting at the east end of the exposure (north side of Route 21) one finds pale green to red to maroon slate with cm-scale interlayers of nonfossiliferous, gray hemipelagic limestone. These strata are similar to the Taconic slates of Stop 3 (yesterday); we would correlate these units directly and argue that the depositional environment is that of the outermost continental rise or deep ocean. The west end of the exposure consists of tan-weathering black slates that are typical of the Tippecanoe Sequence (Middle Ordovician) foreland-basin flysch deposits witnessed yesterday (Stop 8) and earlier today at Stop 9. Milky quartz float occurs at the inferred contact between the variegated- and the black slates and also in both units away from their apparent contact. Here, as in many geologically interesting areas, the actual contact is not exposed, so one cannot use the old eyeballs/brain method to decide if the boundary is lithologic or structural! Based on limited stratigraphic- and structural evidence, we argue that the erosional swale between the varigated (east) and black (west) slates hides a tectonic contact, either the steep frontal snout of Taconic thrust itself, possibly modified by a steep, brittle fault or faults (Figure 30).

Structurally, the rocks have experienced a number of folding events, the oldest of which resulted in long-limbed recumbent isoclinal folds with subhorizontal axial surfaces. The penetrative slaty cleavage in the slates is parallel to, and believed to be contemporaneous with, the sub-horizontal fabric. Throughout most of its extent, the map pattern indicates that the Taconic thrust dips at a low angle. These shallow-dipping recumbent structures, which are typical of the sole thrust areas of the Taconic allochthon, have been refolded by north-plunging folds with westward-dipping axial surfaces as well as by refolded drag folds. The multitude of refolded drag folds may have formed during an episode of steep faulting as argued above and diagrammed in Figure 30.

[21.7] Drive east on Duchess Co. Rd. 21 (Noxon Road).
[22.4] Noxon Road turns left. Continue straight onto Arthursburg Rd.
[23.1] Junction with Taconic State Parkway, take northbound entrance ramp.
[23.6] Green Taconic slate on R. with steep dip to east.
[24.1] Pass over Noxon Road. Slow down for sharp R. turn.
[25.1] Intersection of TSP and Todd Hill Road. Turn R and park on R for quick look at the outcrop of allochthonous Proterozoic gneiss on the E side of TSP just S. of Todd Hill Road. Return to northbound TSP; wait for traffic!
[25.75] Passing Route 55 eastbound to Pawling.
[26.0] Route 55 westbound to Poughkeepsie.
[26.71] Varigated red- and green Taconic slates.
[26.91] Green slates on L.
[26.95] Green slates on R.
[27.0] Passing entrance to James Baird State Park on L.
[27.25] Green slates on L.
[27.6] Green slates on L.
[27.91] Red- and green bedded slates on L.
[28.15] Green slates on R.
[28.3] Green phyllites on L.
[28.8] Green slates (phyllites?) on R.
[29.2] Green slates on both sides of TSP.
[29.85] Green slates with hemipelagic limestone interbeds.
[30.65] Passing intersection of TSP and Rossway Road.
[30.7 to 31.0] Subvertical olive-drab slates.
[31.7] Green slates on R. Leave Pleasant Valley quadrangle and enter Salt Point quadrangle.
[32.0] Green slates on R.
[32.2] Green slates on R.
[33.0] Passing junction of TSP with NY Route 44.
[33.9] Red- and green slates on L.
[34.0] Green slates on L.

[34.92] Deep red slates on L.
[35.4] Red- and green slates.
[35.9] Green slates on L.
[36.1] Green slates on L.
[37.15] Passing jct. TSP with NY Route 115 (Salt Point Turnpike).
[38.15] Green slates on L.
[40.5] Green slates on L.
[40.6] Passing jct. of TSP and Pumpkin Lane.
[40.85] Leave Salt Point quadrangle and enter Rock City quadrangle.
[40.25] Green slates both sides of TSP.
[43.35] Passing jct. TSP with Bulls Head Road.
[44.3] Dark green to black(?) slates on L.
[46.6] Passing jct. TSP with NY Route 199 to Pine Plains and Red Hook.
[46.7] Cuts at interchange. of NY 199 and TSP expose green Taconic slates .
[48.9] Leave Rock City quadrangle and enter Pine Plains quadrangle.
[49.9] Passing jct. TSP and Ferris Road. Up ahead note trees denuded of branches during freak October 1987 snow storm.
[50.4] Leave Rock City quadrangle and enter Ancram quadrangle.
[51.0] More dramatic view of stands of trees damaged during freak October 1987 snow storm.
[51.5] Leave Duchess County and enter Columbia County.
[52.2] Passing jct. TSP with Deer Road.
[53.1] Green phyllite (slate?) on L. with steep easterly dip.
[53.5] Green phyllite.
[54.4] Green slates.
[54.75] Green slates on R.
[54.95] Green slates on both sides of TSP.
[55.4] Pull into Livingston Manor Overlook for brief stop.

Pull-over Stop 10b - Spectacular westward view of Catskill Mountains and Hudson Valley. [UTM Coordinates: 605.40E / 4657.90N, Ancram quadrangle.]

[55.4] Back in vans and continue north on TSP.
[57.8-58.1] Green slates on R.
[58.15] Passing jct. TSP and Lake Taghkanic Road and entrance to Taghkanic State Park on R.
[59.2] At bottom of hill, turn R to leave TSP via ramp to NY Route 82. Follow signs to Rip Van Winkle Bridge.
[59.35] Turn R onto NY Route 82 N. toward Hudson, New York.
[59.7] Turn L across NY 82 to Chief Taghkanic Diner for rest stop and lunch stop.

[59.7] Leave diner parking lot and turn L onto NY 82. Hill immediately on L is a drumlin.
[60.65] Passing Old Oak Road on L.
[61.0] Leave Ancram quadrangle and enter Claverack quadrangle. Drumlin on L.
[61.5] Taconic Orchards on R underlain by drumlin. This follows "Sanders' Law of Apple Orchards" (i. e. - that Hudson Valley orchards are always situated on drumlins!).
[62.2] Dark slates on R.

[62.8] Dark slates on L.
[63.2] Powerline crossing overhead.
[63.4] Leave Claverack quadrangle and enter Hudson South quadrangle.
[63.45] At traffic light, continue straight onto NY Routes 9 and 23 (NY 82 ends). Becraft Mountain is straight ahead.
[65.5] Passing Yates Road on R.
[66.15] Dark slates.
[66.4] Pull over to shoulder for another pull-over stop.

Pull-over Stop 10c - Thinly layered Taconian grayish green slate and hemipelagic limestone. [UTM Coordinates: 600.71E / 4672.72N, Hudson South quadrangle.]

The road cut exposes Taconic slate and interbedded light-gray-weathering hemipelagic limestone similar to Stops 3 and 10 seen earlier. Here, the limestone is very well layered, not metamorphosed, and forms a distinctive Taconic lithology thought to represent continental-rise deposits of hemipelagic limestone. Locally, note the edgewise conglomerate which is clast supported and elsewhere, matrix-supported slabs of carbonate. We interpret these exposures to be the results of oceanward sliding of carbonate from the Cambro-Ordovician shelf sequence into the Taconic oceanic basin. We are here on the Taconic allochthon.

[66.45] Reboard vans and continue straight ahead.
[67.0] Passing Fingar Road on R.
[57.25] Pull over at the intersection of NY Routes 23 and 9 to a large outcrop of carbonates on R, as this is Stop 11.

STOP 11 - Taconic unconformity, bedding thrusts, and late faults, south end of Becraft Mountain. [UTM Coordinates: 599.75E / 4673.42N, Hudson South quadrangle.]

Only a few places exist where budding geologists can place their fingers on the pulse of a former orogeny. In this exposure, the Silurian Rondout Formation rests with angular unconformity on cherts of the Mount Merino Formation (Middle Ordovician Tippecanoe Sequence). The surface of unconformity is quite irregular and the angular discordance between beds above and below is small, perhaps as a result of minor thrust faulting at the Rondout-Mount Merino contact. Within the base of the brown-weathering Roundout (a silty dolostone), however, clasts of black Mount Merino chert and quartz occur. This would be expected if the contact is indeed one of unconformity!

The Rondout is overlain by highly laminated, whitish rocks of the Manlius Formation, but the Rondout appears again above the Manlius. What gives? Bedding thrusts occur within the Rondout and overlying Manlius. The field sketch (Figure 31) shows the bedding thrusts (the lower one outlined by a calcite vein) which imbricate the Siluro-Devonian carbonates above the surface of unconformity with local folding ("rolling") of the Rondout. Again, clear evidence for significant post-Taconic, low-angle thrusting! Toward the south, the Manlius dips below the calc-arenites of the overlying Coeymans Formation and possibly massive limestones of the Kalkberg and New Scotland formations (Table 4) but significant complications are present.

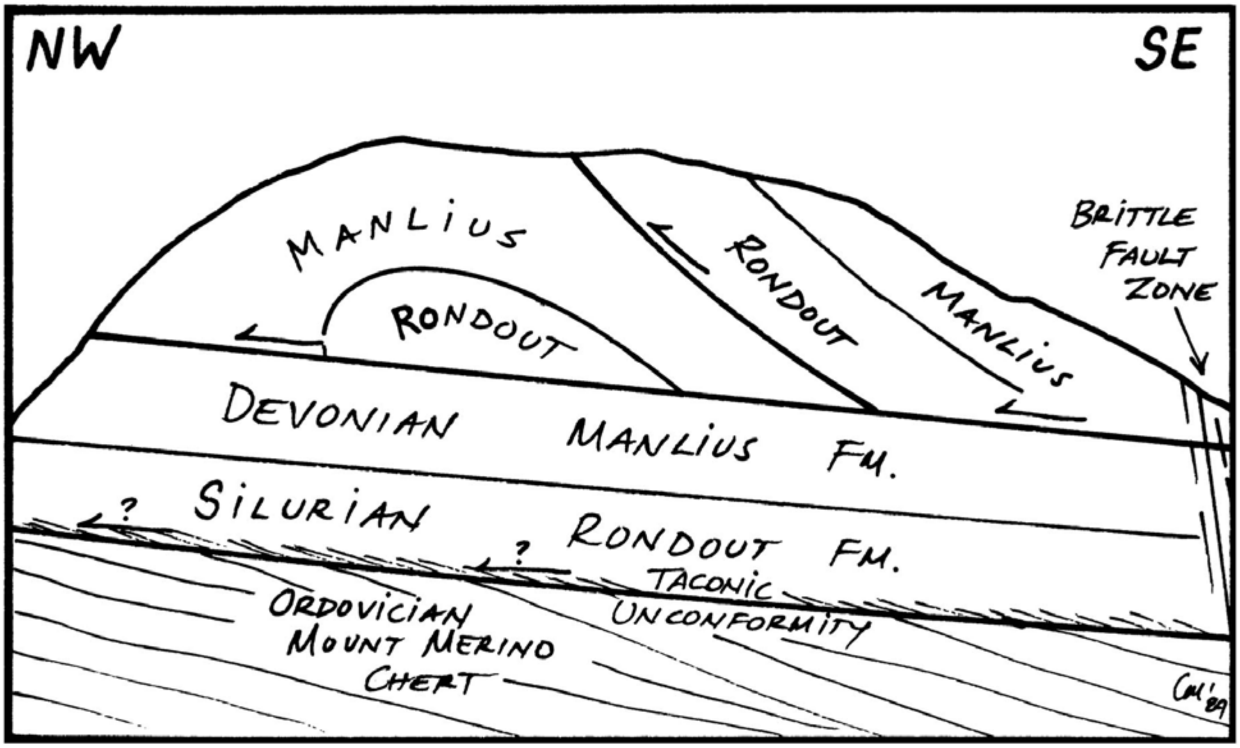


Figure 31 - Diagrammatic sketch of Taconic unconformity and overlying Siluro-Devonian rocks exposed at Becraft Mountain, Stop 11.

Walk southward along the exposure and note the erosional swale in the outcrop and the NE-trending subvertical joints in the carbonates. Immediately south of this broken-up area, coarse calcarenites of the Becraft Formation crop out. Thus, the Becraft had been dropped down along a vertical- to steeply NW-dipping fault (or fault zone) against the Coeymans and/or Kalkberg (see Figure 31). Detailed fossil work needs to be done here to complete the true picture of the structure but clearly high-angle faults (as well as low-angle thrusts) disrupt the "simple flat-lying" sedimentary picture here. What is more, if you assign (as Ruedemann, JES, and CM do) the Mount Merino cherts to the Tippecanoe Sequence, then between pull-over stop 4 and here we have left behind the Taconic Sequence on the Taconic allochton and have crossed a major tectonic contact (either the Taconic thrust itself or this thrust plus a later high-angle fault)! As we shall see momemtarily, the allochthonous Taconic rocks are lurking not too far away! (The overall relationships between the subunconformity Tippecanoe Sequence and Taconic Sequence here resemble those at Stop 10, Noxon Road.)

Surfaces of unconformity mark gaps in the geologic record and result from periods of uplift and erosion. Such uplift and erosion is commonly caused by the terminal phase of regional mountain-building episodes. Here, Middle Ordovician cherts and slates of the Tippecanoe Sequence are overlain by Siluro-Devonian carbonate rocks of the Helderberg Group (Layer IIIW in Table 2). The Helderbergian strata form a significant outcrop belt throughout New York State and have historically provided a ready source of lime for cement manufacturers. Farther west, the Helderberg limestones are overlain by clastics which coarsen upwards into the continental Catskill red-bed facies. A regional cross section, sketched in Figure 32, shows the Catskill front overlying the Helderberg strata which, in turn, rest unconformably on the eroded Taconian orogenic belt. Thus, after the main phase Taconic orogenic event of roughly 450 Ma (Table 1), the North American shelf edge returned to the calm of near-equatorial carbonate deposition as it awaited the next tectonic event. That event, the Acadian orogeny, arrived in short order (Tables 1, 2) at roughly 360 Ma.

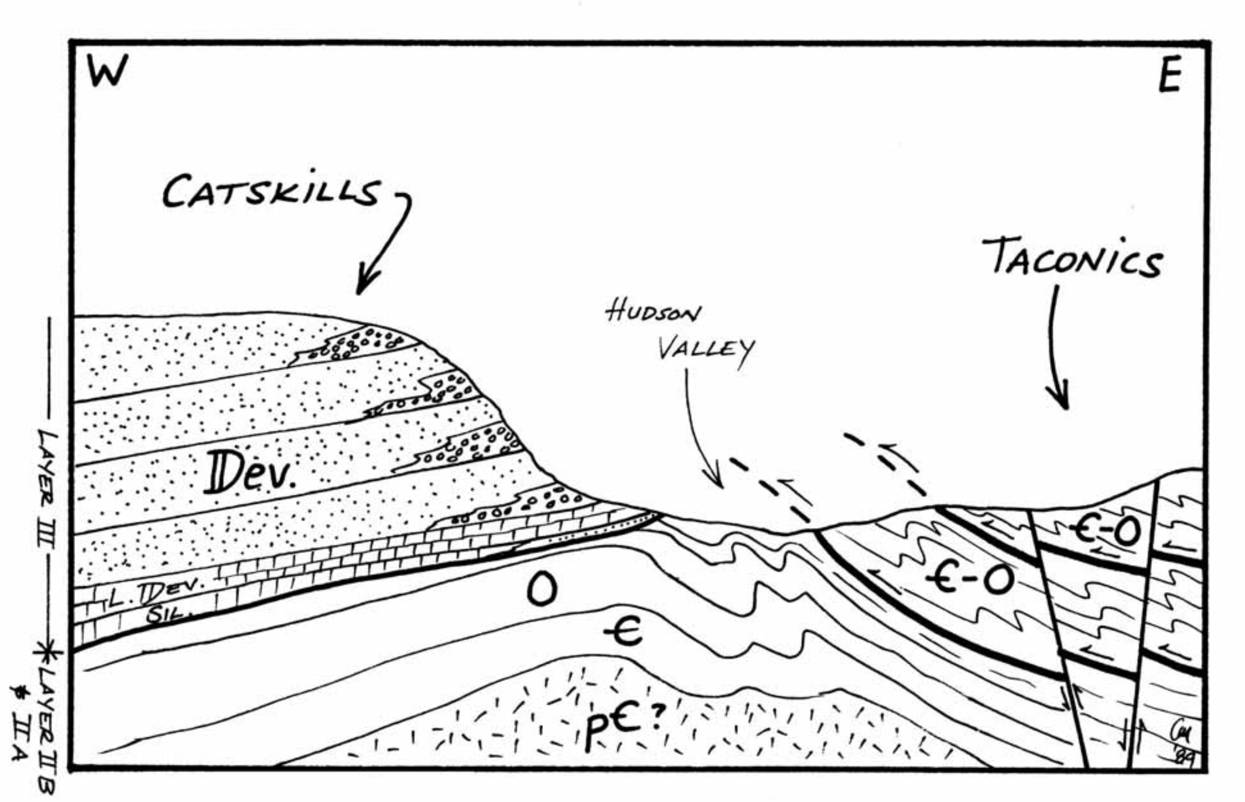


Figure 32 - Diagrammatic west-east geologic cross-section of the Hudson Valley and Catskill front.

[67.25] Reboard vans, turn around in triangle and drive south on NY Route 23.
[67.55] Turn L onto Fingar Road.
[67.95] Passing Old Time Power Ass'n on L. Bring your used, old tractors here!
[68.25] Four corners intersection. Turn L. onto Hiscox Road (not Neuman Rd.).
[68.35] Steeply dipping Siluro-Devonian carbonates forming east limb of syncline that underlies Becraft Mountain. We are immediately east of Stop 11 now.
[68.95] Outcrop of Becraft limestone on L. Allochthonous Taconic slates underlie open fields to R.
[69.25] Junction with Columbia County Road 29. Turn L. onto Co. Rd. 29.
[69.45] Beginning of outcrops of Stop 12 but continue north on Co. Rd. 29 as we will turn around and come back.

[69.85] Pull over to rest area near bend in Claverack Creek, turn vans around and retrace steps (head south).
[70.15] Pull over on wide shoulder for Stop 12.

STOP 12 - Taconic unconformity and other goodies, east side of Becraft Mountain. [UTM Coordinates: 602.53E / 4674.95N, Hudson South quadrangle.]

Starting at the south end of this exposure on the east side of Becraft Mountain, we find support for our previous interpretations at Stop 11 and find the Rondout in profound angular unconformity with older strata below. But here, the older strata do not belong to the Tippecanoe Sequence, as at Stop 11, but consist of typical variegated red- and green allochthonous Taconic slates. Here, we are on the eastern limb of a syncline (which underlies Becraft Mountain) with the Rondout bedding parallel to the surface of unconformity, both being oriented N25°E, 34°NW. The slaty cleavage in the Taconic rocks trends N85°E, 70°SE.

Walk northward along the road and note the change in orientation of the Taconic slaty cleavage beneath the surface of unconformity and the fact that the Manlius begins to crop out in the hillside above the Rondout. The contact between the Rondout and Manlius is gradational between the gray-weathering, laminated Manlius and tan-weathering Rondout. Farther north the dip of the bedding steepens and the stratigraphic relationships have been complicated by low-angle bedding-plane thrusts and high-angle solution cleavage (probably related to folding of the Becraft syncline). The Coeymans and Kalkberg crop out nearer the top of the hillside. Again, these exposures support our contention that two significant episodes of low-angle thrusting occurred before high-angle faulting and gentle folding of the Helderbergian strata. The relative ages of these events are known (post-Middle Ordovician low-angle Taconic thrusts, followed by post-Taconic low-angle thrusts, followed by high-angle faulting) but the absolute ages await further investigation. Onward to bigger and better things!

[70.15] Reboard vans and follow County Road 29 south.
[70.35] Pass Hiscox Road on R, stay on Co. Rd. 29. Nice view of Catskill front on R.
[71.95] Powerline crossing.
[72.15] Turn L onto NY Routes 9H and 23.
[72.25] Leave Hudson South quadrangle and re-enter Claverack quadrangle.
[72.5] Powerline crossing, veer right onto School House Road.
[72.95] Orchard on crest of drumlin.
[73.7] Taconic slates on L.
[73.85] Go straight across County Road 27 and follow School House Road (Co. Rd. 27B).
[74.65] Pass over Loomis Creek.
[75.35] Continue straight on Co. Rd. 16 toward junction with NY Route 23.
[75.65] Beautiful downtown Hollowville.
[75.8] Green slates all over.
[76.85] Merge with NY Route 23 (east). Till exposed on L.
[78.55] Junction with Taconic State Parkway. Rest stop to R!

[78.75] Taconic slates on R.
[78.85] Junction with Philmont Road.
[79.95] Taconic slates.
[80.45] Leave Claverack quadrangle and enter Hillsdale quadrangle (approximately located).
[81.25] View of Berkshire Mountains of Massachusetts ahead.
[85.35] Enter Hillsdale town limits.
[85.85] Turn R onto NY Route 22 in the center of Hillsdale and follow south. Great view of High Taconics ahead and to L.
[86.5] Pass over Roeliff Jansen Kill.
[87.75] NY Central Railroad overpass.
[89.05] Deep cleft in ridge to the L is Bashbish Falls, our next stop.
[89.85] Turn left onto NY Route 344 (leave NY 22) toward Copake Falls. Leave Hillsdale quadrangle and enter Copake quadrangle.
[90.25] Sharp turn to L to follow NY 344.
[90.6] Stay on low road to R past entrance (on L) to Taconic State Park.
[90.65] Follow road to L toward Bashbish Falls.
[91.3] Pull over to R into trailhead parking area for Stop 13.

STOP 13 - Evidence of progressive metamorphism in the Paleozoic Everett Phyllite, Bashbish Falls, Copake, New York and Massachusetts. [UTM Coordinates: N/A, Bashbish Falls quadrangle.]

Be prepared for a half-hour eastward stroll along the north side of Bashbish Creek. Note the nature of the rocks on the trail. These are Taconic slates and phyllites described by Zen and Hartshorn (1966). Near the trailhead the rocks are greenish slates and phyllites rich in chlorite mica. Near Bashbish Falls, the rocks are decidedly of higher metamorphic grade with porphyroblasts of garnet and staurolite sticking up out of the foliation surface and forming a spotted schist. Thus the complete metamorphic lithologic transition from slate to phyllite to schist can be observed along our walk.

By the time you reach Bashbish Falls, you have crossed the New York-Massachusetts state line (surrender all firearms!). At the falls, note the foliation on the steeply dipping Everett Schist. According to Zen and Hartshorn, the Everett formation is mainly a quartzose argillite but in the vicinity of Bashbish Falls, it has been transformed into an albite-almandine-chloritoid-chlorite-muscovite-ilmenite schist and a coarse calcic albite-ilmenite-almandine-staurolite-chlorite-muscovite quartz schist reflecting the increased metamorphic grade in the area. The Everett is considered to be of Cambrian to Ordovician age and part of the Taconic allochthon. It rests structurally upon the bedrock of the autochthon consisting of the Walloomsac (=Egremont Phyllite), and underlying Stockbridge Marble. See Table 5 for lithologic correlations with adjacent areas.

[91.3] Reboard vans and turn L out of parking area onto NY 344.
[92.0] Pass Depot Deli on L.
[92.25] Turn L at stop sign to NY 344 (southbound).

[92.5] Turn L at stop sign to rejoin NY 22 (southbound).
[93.3] Marble outcrop on R.
[95.1] Slates on L. Berkshire massif farther to L.
[96.5] Under Mountain Road on L.
[96.9 - 97.1] Slates (phyllites?) on R. Stockbridge Marble occupies valley to left in front of Berkshire Proterozoic massif. Here, and along much of the Berkshire front, continentward thrust faulting (Taconian, of Mid-Ordovician age), has been demonstrated by Harwood (1975) and by Ratcliffe and Harwood (1975).
[99.4] Passing Whitehouse Road on L.
[99.6] Slates on R. (plus marble?)
[100.4] Black slates on R (=Walloomsac?)
[100.85] Leave Columbia County, enter Duchess County.
[101.8] Passing jct. with Duchess County Road 62 on L. (Entrance to Rudd Pond).
[104.4] Enter village of Millerton.
[104.9] At traffic light (jct. NY 22 and US Route 44). follow NY 44 (west) and NY 22 (south).
[106.45] Passing jct. of NY 22 and NY Route 199, road to Stissing Mountain to R. This is the area first discussed by E. B. Knopf (1927, 1946, 1962) wherein she described Stissing Mountain as an uplifted block of Proterozoic gneiss surrounded by Paleozoic carbonates and Taconic slates. Here, the uplift has taken place along steep, brittle post-Taconic faults.

[107.9 - 108.0] Well-bedded, flat-lying Paleozoic marble (Copake limestone?).
[108.7] Passing jct. NY 22-US Route 44 with Co. Rd. 5 on R. Carbonate outcrop on L.
[110.5] Carbonate outcropping on both sides of road.
[111.0] Flat-lying carbonates on R.
[112.0] Slates on R.
[113.0] Entering Amenia, NY.
[113.5] Turn R where NY 44W pulls off in the center of Amenia.
[115.55] Slates on R.
[115.65] Passing jct. with NY Route 83 on R to Pine Plains.
[115.9] Slates on R.
[121.5] Enter Mabbettsville.
[121.8] County Rds. 98 and 99 cross NY 44.
[123.2] Go straight (follow Route 44A). Route 44 curves L.
[126.3] Junction with NY 44. Turn R to rejoin NY 44 and 82 (west).
[127.4] Follow NY 44 to L at ATI gas station. NY 82 splits off to R.
[128.25] Junction with Taconic State Parkway. Take TSP southbound entrance ramp. Note Taconic slates all around cloverleaf.
[128.2] Pull onto TSP southbound.

END OF DETAILED ROAD LOG! - OFFICIAL END OF TRIP

South of I-84, on either side of the TSP and Bronx River Parkway, note the increase in metamorphic grade of the Taconic rocks from slates and phyllites into schists and gneisses. Because we are travelling southward within the Manhattan Prong, it should come as no surpise that the highly metamorphosed upper member of the Manhattan Schist and structurally higher Hartland Formation in New York City (as seen on On-The-Rocks Trip 03, November 1988) are the direct correlatives of the Taconic allochthonous rocks viewed on our two-day Taconic field trip. We hope you enjoyed our On-The-Rocks trip to the Taconics and hope to see you again on our next wilderness experience to the Delaware Water Gap.

To return to NYAS - Follow TSP southbound, past I-84 to the Bronx River Parkway. Follow Bronx River Parkway south to Cross Bronx Expressway. Take Cross Bronx to Harlem River (East Side) Drive to NYAS.

UNOFFICIAL TRIP STOPS

In the event you try this trip again on your own, there are two stops described below (that we will not have time to visit, officially) that will round out the picture of progressive metamorphism along Route 55 in Duchess County. This split off from the TSP (for NY 55, eastbound) occurs before the junction with I-84. Figure 33 is a road and geologic map from Bence and McLelland (1976) showing the two supplemental field stops described below which illustrate the metamorphosed equivalents of the Sauk Sequence (Layer IIA) strata observed yesterday. Mileages are approximate from the TSP!

[0.0]	Exit TSP onto NY Route 55 eastbound.
[0.9]	Junction with NY Route 82, stay on NY 55.
[3.6]	Junction with Wingdale Road, stay on NY 55.
[11.0]	Exposures of Wallomsac schists, Stop 14.

STOP 14 - The Walloomsac Formation (Tippecanoe Sequence, mid Ordovician), NY Route 55. [UTM Coordinates: 613.40E / 4602.51N, Poughquag quadrangle.]

According to Bence and McLelland (1976; Stop 6 NYSGA), the rocks in these long roadcuts have been mapped as Walloomsac Schist (thus an assignment to the Tippecanoe Sequence), but in their own words, "whether they are, or not, is open to question." The rocks are interpreted as being metamorphosed pelitic (clay-rich) sediments with biotite-rich schists predominating. Quartzose and granular quartzofeldspathic layers and lenses are interlayered with the schist and locally outline early isoclinal folds. The earliest structures are NE-trending isoclinal folds which are folded by tight to isoclinal NE-trending folds with N30°-40°E axial surfaces which dip 50° SE. A third set of open N-S-trending folds redeforms these earlier structures, and produces kinking and crenulation cleavage in the rock.

Of metamorphic interest here, the biotite-rich schist contains garnet and kyanite, both indicators of amphibolite-facies metamorphism. The kyanite occurs as bluish blades, 3 mm to 2 cm long, particularly concentrated within more-micaceous layers. Overthickening of the mica + kyanite layers in the hinge areas of folds has developed kyanite-rich pods that can be seen best on the top of the roadcut where weathering has made the kyanite most visible. In addition, quartzose bands are extremely rich in garnet; and hornblende-bearing pods also occur perhaps as a result of original bulk chemical variations in the original sediment.

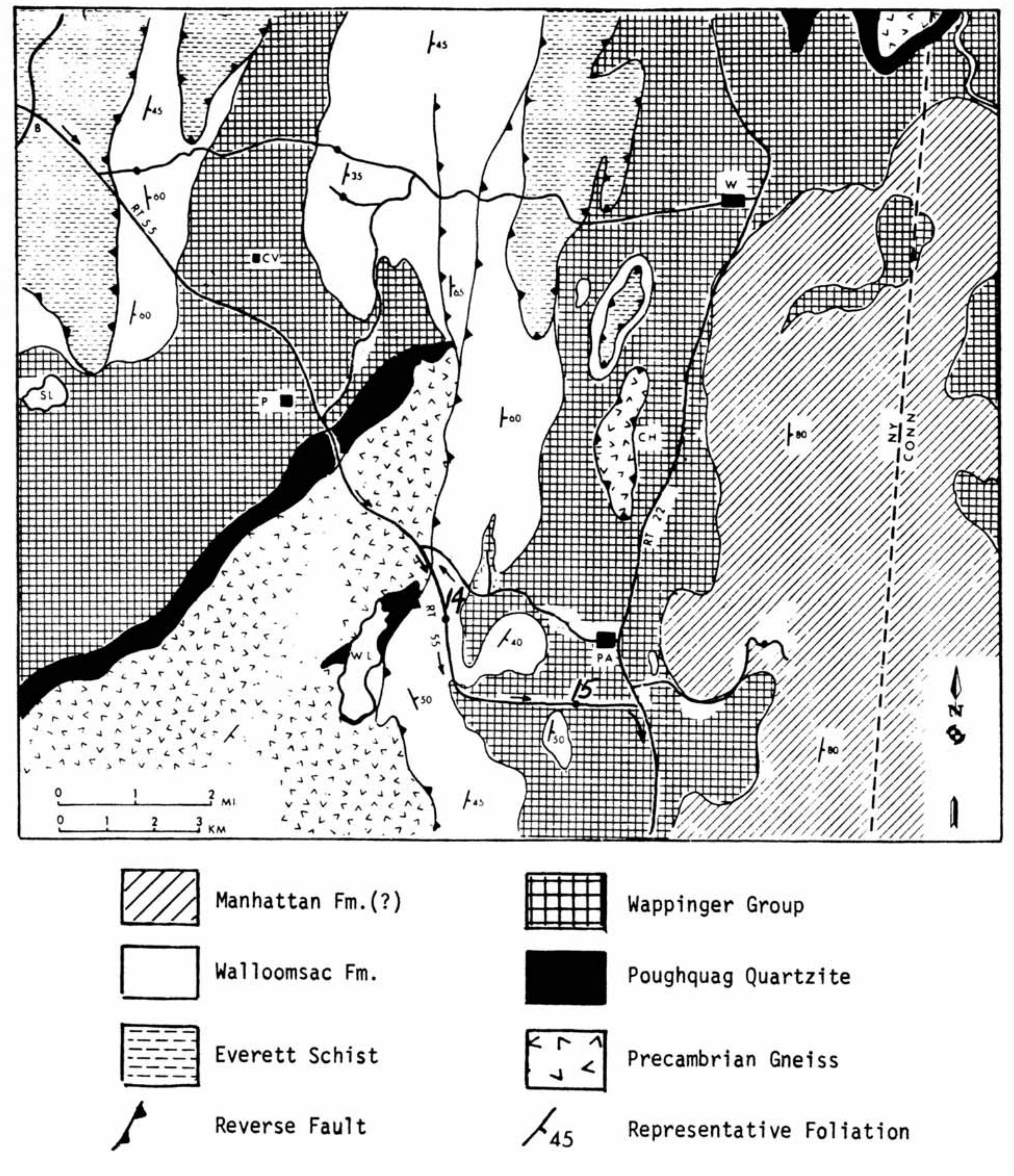


Figure 33 - Geologic sketchmap of the Wallomsac Formation and Briarcliff Dolostone in Duchess County, New York (Unofficial Stops 14 and 15) from Bence and McLelland (1976).

[11.0] Continue eastbound on NY 55.
[14.1] Cuts on both sides of NY 55, Stop 15.

STOP 15 - Metamorphosed Briarcliff Dolostone (Sauk Sequence, Cambrian to Ordovician), NY Route 55. [UTM Coordinates: 616.07E / 4600.79N, Pawling quadrangle.]

To end our transect trip across the southern- and central Taconics we would like to show how the effects of metamorphism increase rapidly from northwest to southeast across the Taconide zone. Remember back to our detailed views of the Sauk Sequence (Cambrian to Ordovician shelf deposits) yesterday. If not, refer back to the descriptions of Stops 2, 4, and 7 and consult the map showing locations of field-trip stops (Figure 16). Note that we are less than 15 miles (9 km) from our easternmost stop (Stop 4) in the Wappinger Group. Here, in an outcrop described by Bence and McLelland (1976; Stop 7 NYSGA) and McLelland and Fisher (1976; Stop 7 NYSGA) metamorphosed equivalents of the Sauk Sequence (Layer IIA(W) are exposed in cuts on either side of the road.

Along either side of Route 55 (Figure 33), large cuts show gray-weathering, light-colored Briarcliff Dolostone with yellow, white, and black chert layers up to 5 cm thick. Accessory minerals include quartz, phlogopite, tremolite, diopside, and local serpentine. Structurally, tight to isoclinal folds, which occur in the dolostone with generally shallow axial surfaces, refold an earlier phlogopite foliation. These early fabrics are refolded by NNE-trending folds with steep plunges and a younger set of N-S-trending upright, dominantly open folds. Note disharmonic folds develped because of the profound differences in mechanical behavior between the ductile marble and brittle siliceous layers.

Petrologically, this stop is of interest because it affords the opportunity to examine the development of calc-silicates at grades approaching the first sillimanite isograd. Throughout the roadcut diopside, tremolite, and phlogopite are abundantly developed in the appropriate lithologies and are best seen on the weathered surface at the top of the roadcut. At the top of the roadcut near its eastern end a 0.8-meter-wide layer contains coarse tablets, blades, and rosettes of white tremolite. The layer can be followed for more than 15 m. Thus, rather strong recrystallization from progressive metamorphism, of original carbonate-rich sediments has resulted in a major change in the minerals.

Regionally, these relationships indicate that in a very short distance metamorphic grade increases rapidly from west to east. Ratcliffe (1984) argues that steepened metamorphic isograds in this region are the result of tight, asymmetric folding of the isograds along steeply dipping limbs. In concert, or perhaps alternatively, the data could be interpreted to indicate more uplift to the east, with originally deeper rocks now exposed at the surface, perhaps in response to high-angle brittle faulting.

OFFICIAL END OF UNOFFICIAL END OF TRIP

Alternate driving directions back to the Academy:

Drive eastward on NY Route 55 to the intersection with NY Route 22 (roughly 1.0 mi.). Take NY Route 22 south to the intersection with Routes I-84 and I-684. Follow Route I-684 south to the Saw Mill River Parkway to Route I-87 south (Major Deegan Expressway) into Manhattan.

ACKNOWLEDGEMENTS

We dedicate this field trip to diners in New England. Without their hospitality, coffee, danish, bread pudding, and restrooms, our fieldtrips would become untenable. Special thanks to Professor Baiying Guo, Visiting Research Geologist at Northeastern Science Foundation, Troy, from Huainan Mining Institute, PRC, for assisting JES on several pre-trip excursions and for making available her unpublished studies of the Sauk Sequence penetrated by the Crom-Wells No. 1 Fee boring, Middletown, Orange Co., NY. Financial support for the research on the Sauk Sequence in eastern New York being undertaken by Prof. Guo and JES has been via a grant from the New York Gas Group to the Northeastern Science Foundation. As usual, Matt Katz and Marcie Brenner at the New York Academy have controlled and managed most of the administrative details for the On-The-Rocks field-trip series. Christopher Merguerian helped us find "big rocks" on our pre-trip field excursions.

TABLES

Table 01 - GEOLOGIC TIME CHART

(with selected major geologic events from southeastern New York and vicinity)

ERA **Periods (Epochs)**	**Years (Ma)**	**Selected Major Events**
CENOZOIC		
(Holocene)	0.1	Rising sea forms Hudson Estuary, Long Island Sound, and other bays. Barrier islands form and migrate.
(Pleistocene)	1.6	Melting of last glaciers forms large lakes. Drainage from Great Lakes overflows into Hudson Valley. Dam at The Narrows suddenly breached and flood waters erode Hudson shelf valley. Repeated continental glaciation with five? glaciers flowing from NW and NE form moraine ridges on Long Island.
(Pliocene)	6.2	Regional uplift, tilting and erosion of coastal-plain strata; sea level drops. Depression eroded that later becomes Long Island Sound.
(Miocene)	26.2	Fans spread E and SE from Appalachians and push back sea. Last widespread marine unit in coastal-plain strata.
MESOZOIC	66.5	
(Cretaceous)		
	96	Passive eastern margin of North American plate subsides and sediments (the coastal-plain strata) accumulate.
	131	(**Begin Atlantic Passive-Margin Stage II**).
(Jurassic)		Baltimore Canyon Trough forms and fills with 8,000 feet of pre-Cretaceous sediments.
		Atlantic Ocean starts to open. Newark basins deformed, arched, eroded.
(Triassic)	190	Continued filling of subsiding Newark basins and mafic igneous activity both extrusive and intrusive.
		Newark basins form and fill with non-marine sediments.

PALEOZOIC	245	
(Permian)		Pre-Newark erosion surface formed.
	260	**Appalachian orogeny.** (Terminal stage.) Folding, overthrusting, and metamorphism of Rhode Island coal basins; granites intruded.
(Carboniferous)		Faulting, folding, and metamorphism in New York City area. Southeastern New York undergoes continued uplift and erosion.
(Devonian)	365	**Acadian orogeny.** Deep burial of sedimentary strata. Faulting, folding, and metamorphism in New York City area. Peekskill Granite and Acadian granites intruded.
(Silurian)		
	440	**Taconic orogeny.** Intense deformation and metamorphism.
	450	Cortlandt Complex and related rocks intrude Taconian suture zone. (Cameron's Line and St. Nicholas Thrusr Zone). Arc-continent collision. Great overthrusting from ocean toward continent. Taconic deep-water strata thrust above shallow-water strata.
(Ordovician)		Ultramafic rocks (oceanic lithosphere) sliced off and transported structurally above deposits of continental shelf.
(Cambrian)		Shallow-water clastics and carbonates accumulate in west of basin. (= **Sauk Sequence**; protoliths of the Lowerre Quartzite, Inwood Marble, Walloomsac Schist). Transitional slope/rise sequence (Manhattan Schist) and deep-water terrigenous strata (Hartland Formation) form to east. (= **Taconic Sequence**).
PROTEROZOIC		
	570	Period of uplift, rifting,and erosion followed by subsidence of margin and development of **Iapetan Passive-Margin Stage I**.
(Z)	600	Rifting with rift sediments, volcanism, and intrusive activity. (Ned Mountain, Pound Ridge, and Yonkers gneiss protoliths).
(Y)	1100	**Grenville orogeny.** Sediments and volcanics deposited, compressive deformation, intrusive activity, and granulite facies metamorphism. (Fordham Gneiss, Hudson Highlands and related rocks).
ARCHEOZOIC		
	2600	No record in New York.
	4600	Solar system (including Earth) forms.

Table 02 - Generalized Descriptions of Major Geologic "Layers", SE New York State and Vicinity

This geologic table is a tangible result of the On-The-Rocks Field Trip Program conducted by Drs. John E. Sanders and Charles Merguerian between 1988 and 1998. In Stenoan and Huttonian delight, we here present the seven layer cake model that has proved so effective in simplifying the complex geology of the region. Under continual scrutiny and improvement, we provide this updated web-based information as a public service to all students and educators of geology. We encourage any comments, additions, or corrections. References cited can be sought by following this link.

LAYER VII - QUATERNARY SEDIMENTS

A blanket of irregular thickness [up to 50 m or more] overlying and more or less covering all older bedrock units. Includes four or five tills of several ages each of which was deposited by a continental glacier that flowed across the region from one of two contrasting directions: (1) from N10°E to S10°W (direction from Labrador center and down the Hudson Valley), or (2) from N20°W to S20°E (direction from Keewatin center in Hudson's Bay region of Canada and across the Hudson Valley). The inferred relationship of the five tills is as follows from youngest [I] to oldest [V]. [I] - Yellow-brown to gray till from NNE to SSW, [II] - red-brown till from NW to SE, [III] - red-brown till from NW to SE, and [IV] - yellow-brown to gray till from NNE to SSW, and [V] - red-brown till from NW to SE containing decayed stones (Sanders and Merguerian, 1991a,b, 1992, 1994a, b; Sanders, Merguerian, and Mills, 1993; Sanders and others, 1997; Merguerian and Sanders, 1996). Quaternary sediments consist chiefly of till and outwash. On Long Island, outwash (sand and gravel) and glacial lake sediment predominates and till is minor and local. By contrast, on Staten Island, tills and interstratified lake sediments predominate and sandy outwash appears only locally, near Great Kills beach.

[Pliocene episode of extensive and rapid epeirogenic uplift of New England and deep erosion of major river valleys, including the excavation of the prominent inner lowland alongside the coastal-plain cuesta; a part of the modern landscape in New Jersey, but submerged in part to form Long Island Sound].

~~~~~~~~~~~~~~~~~~~~Surface of unconformity~~~~~~~~~~~~~~~~~~~~

LAYER VI - COASTAL-PLAIN STRATA (L. Cretaceous to U. Miocene; products of Passive Continental Margin II - Atlantic).

Marine- and nonmarine sands and clays, present beneath the Quaternary sediments on Long Island (but exposed locally in NW Long Island and on SW Staten Island) and forming a wide outcrop belt in NE New Jersey. These strata underlie the submerged continental terrace. The basal unit (L. Cretaceous from Maryland southward, but U. Cretaceous in vicinity of New York City) overlaps deformed- and eroded Newark strata and older formations. Also includes thick (2000 m) L. Cretaceous sands and shales filling the offshore Baltimore Canyon Trough. At the top are Miocene marine- and coastal units that are coarser than lower strata and in many localities SW of New Jersey, overstep farther inland than older coastal-plain strata. Capping unit is a thin (<50 m) sheet of yellow gravel (U. Miocene or L. Pliocene?) that was prograded as SE-directed fans from the Appalachians pushed back the sea. Eroded Newark debris is present in L. Cretaceous sands, but in U. Cretaceous through Miocene units, Newark-age redbed debris is conspicuously absent. This relationship is considered to be proof that the coastal-plain formations previously buried the Newark basins so that no Newark-age debris was available until after the Pliocene period of great regional uplift and erosion. The presence of resistant heavy minerals derived from the Proterozoic highlands part of the Appalachians within all coastal-plain sands indicates that the coastal-plain strata did not cover the central highlands of the Appalachians.

[Mid-Jurassic to Late Jurassic episode of regional arching of Newark basin-filling strata and end of sediment accumulation in Newark basin; multiple episodes of deformation including oroclinal "bending" of entire Appalachian chain in NE Pennsylvania (Carey, 1955), and one or more episodes of intrusion of mafic igneous rocks, of folding, of normal faulting, and of strike-slip faulting (Merguerian and Sanders, 1994b). Great uplift and erosion, ending with formation of Fall-Zone planation surface].

~~~~~~~~~~~~~~~~~~~~Surface of unconformity~~~~~~~~~~~~~~~~~~~~

LAYER V - NEWARK BASIN-FILLING STRATA (Upper Triassic and Lower Jurassic)

Newark-age strata unconformably overlie folded- and metamorphosed Paleozoic strata of Layer II and some of the Proterozoic formations of Layer I; are in fault contact with other Proterozoic formations of the Highlands complex. Cobbles and boulders in basin-marginal rudites near Ramapo Fault include mostly rocks from Layers III, IIB, and IIA(W), which formerly blanketed the Proterozoic now at the surface on the much-elevated Ramapo Mountains block. The thick (possibly 8 or 9 km) strata filling the Newark basin are nonmarine.

In addition to the basin-marginal rudites, the sediments include fluvial- and varied deposits of large lakes whose levels shifted cyclically in response to climate cycles evidently related to astronomic forcing. A notable lake deposit includes the Lockatong Formation, with its analcime-rich black argillites, which attains a maximum thickness of about 450 m in the Delaware River valley area. Interbedded with the Jurassic part of the Newark strata are three extrusive complexes, each 100 to 300 m thick, whose resistant tilted edges now underlie the curvilinear ridges of the Watchung Mountains in north-central New Jersey. Boulders of vesicular basalt in basin-marginal rudites prove that locally, the lava flows extended northwestward across one or more of the basin-marginal faults and onto a block that was later elevated and eroded. The thick (ca. 300 m) Palisades intrusive sheet is concordant in its central parts, where it intrudes the Lockatong at a level about 400 m above the base of the Newark strata. To the NE and SW, however, the sheet is discordant and cuts higher strata (Merguerian and Sanders, 1995a). Contact relationships and the discovery of clastic dikes at the base of the Palisades in Fort Lee, New Jersey, suggest that the mafic magma responsible for the Palisades was originally intruded at relatively shallow depths (roughly 3 to 4 km) according to Merguerian and Sanders (1995b).

Xenoliths and screens of both Stockton Arkose and Lockatong Argillite are present near the base of the sill. Locally, marginal zones of some xenoliths were melted to form granitic rocks (examples: the trondhjemite formed from the Lockatong Argillite at the Graniteville quarry, Staten Island, described by Benimoff and Sclar, 1984; and a "re-composed" augite granite associated with pieces of Stockton Arkose at Weehawken and Jersey City, described by J. V. Lewis, 1908, p. 135-137).

[**Appalachian terminal orogeny**; large-scale overthrusts of strata over strata (as in the bedding thrusts of the "Little Mountains east of the Catskills" and in the strata underlying the NW side of the Appalachian Great Valley), of basement over strata (in the outliers NW of the Hudson Highlands, and possibly also in many parts of the Highlands themselves), and presumably also of basement over basement (localities not yet identified). High-grade metamorphism of Coal Measures and intrusion of granites in Rhode Island dated at 270 Ma. Extensive uplift and erosion, ending with the formation of the pre-Newark peneplain].

~~~~~~~~~~~~~~~~~~~Surface of unconformity~~~~~~~~~~~~~~~~~~~

LAYER IV - COAL MEASURES AND RELATED STRATA (Carboniferous)

Mostly nonmarine coarse strata, about 6 km thick, including thick coals altered to anthracite grade, now preserved only in tight synclines in the Anthracite district, near Scranton, NE Pennsylvania; inferred to have formerly extended NE far enough to have buried the Catskills and vicinity in eastern New York State (Friedman and Sanders, 1982, 1983).

[**Acadian orogeny**; great thermal activity and folding, including metamorphism on a regional scale, ductile deformation, and intrusion of granites; dated at ~360 Ma].

LAYER III - MOSTLY MARINE STRATA OF APPALACHIAN BASIN AND CATSKILLS (Carbonates and terrigenous strata of Devonian and Silurian age)

(Western Facies)	**(Eastern Facies)**
Catskill Plateau, Delaware Valley monocline, and "Little Mountains" NW of Hudson-Great Valley lowland.	SE of Hudson-Great Valley lowland in Schunnemunk-Bellvale graben.
Kaaterskill redbeds and cgls.	Schunnemunk Cgl.
Ashokan Flags (large cross strata)	Bellvale Fm., upper unit
Mount Marion Fm. (graded layers, marine)	Bellvale Fm., lower unit (graded layers, marine)
Bakoven Black Shale	Cornwall Black Shale

Onondaga Limestone	
Schoharie buff siltstone	Pine Hill Formation
Esopus Formation	Esopus Formation
Glenerie Chert	
Connelly Conglomerate	Connelly Conglomerate
Central Valley Sandstone	
Carbonates of Helderberg Group	Carbonates of Helderberg Group
Manlius Limestone	
Rondout Formation	Rondout Formation
Decker Formation	
Binnewater Sandstone	Poxono Island Formation
High Falls Shale	Longwood Red Shale
Shawangunk Formation	Green Pond Conglomerate

[**Taconic orogeny**; 480 Ma deep-seated folding, dynamothermal metamorphism and mafic- to ultramafic (alkalic) igneous intrusive activity (dated in the range of 470 to 430 Ma) across suture zone (Cameron's Line-St. Nicholas thrust zones). Underthrusting of shallow-water western carbonates of Sauk Sequence below supracrustal deep-water eastern Taconic strata and imbrication of former Sauk-Tippecanoe margin. Long-distance transport of strata over strata has been demonstrated; less certain locally is proof of basement thrust over strata and of basement shifted over basement. In Newfoundland, a full ophiolite sequence, 10 km thick, has been thrust over shelf-type sedimentary strata]. In NYC and throughout New England, dismembered ophiolite is common (Merguerian 1979; Merguerian and Moss 2005, 2007).

~~~~~~~~~~~~~~~~~~~~Surface of unconformity~~~~~~~~~~~~~~~~~~~~

LAYER II - CAMBRO-ORDOVICIAN CONTINENTAL-MARGIN COVER (Products of Passive Continental Margin I - Iapetus). Subdivided into two sub layers, IIB and IIA. Layer IIA is further subdivided into western- and eastern facies.

LAYER IIB - TIPPECANOE SEQUENCE - Middle Ordovician flysch with basal limestone (Balmville, Jacksonburg limestones).

Not metamorphosed / Metamorphosed
Martinsburg Fm. / Walloomsac Schist
Normanskill Fm. / Annsville Phyllite

Subaerial exposure; karst features form on Sauk (Layer IIA[W]) platform.

~~~~~~~~~~~~~~~~~~~~Surface of unconformity~~~~~~~~~~~~~~~~~~~~

LAYER IIA [W] - SAUK SEQUENCE	**LAYER IIA [E] - TACONIC SEQUENCE**
Western shallow-water platform	**Eastern deep-water zone**
(L. Cambrian - M. Ordovician)	(L. Cambrian-M. Ordovician)
Copake Limestone (Stockbridge,	
Rochdale Limestone (Inwood Marble)	
Halcyon Lake Fm.	
Briarcliff Dolostone	(Ꞓ-Oh) Hartland Fm.
Pine Plains Fm.	(Ꞓ-Om) Manhattan Fm.
Stissing Dolostone	
Poughquag Quartzite	
Lowerre Quartzite	
Ned Mtn Fm.	

[**Pre-Iapetus Rifting Event**; extensional tectonics, volcanism, rift-facies sedimentation, and plutonic igneous activity precedes development of Iapetus ocean basin. Extensional interval yields protoliths of Pound Ridge Gneiss, Yonkers granitoid gneisses, and the Ned Mountain Formation (Brock, 1989, 1993). In New Jersey, metamorphosed rift facies rocks are mapped as the Chestnut Hill Formation of A. A. Drake, Jr. (1984)].

~~~~~~~~~~~~~~~~~~~~Surface of unconformity~~~~~~~~~~~~~~~~~~~~

LAYER I - PROTEROZOIC BASEMENT ROCKS

Many individual lithologic units including Proterozoic Z and Y ortho- and paragneiss, granitoid rocks, metavolcanic- and metasedimentary rocks identified, but only a few attempts have been made to decipher the stratigraphic relationships; hence, the three-dimensional structural relationships remain obscure. Followed by a period of uplift and erosion.

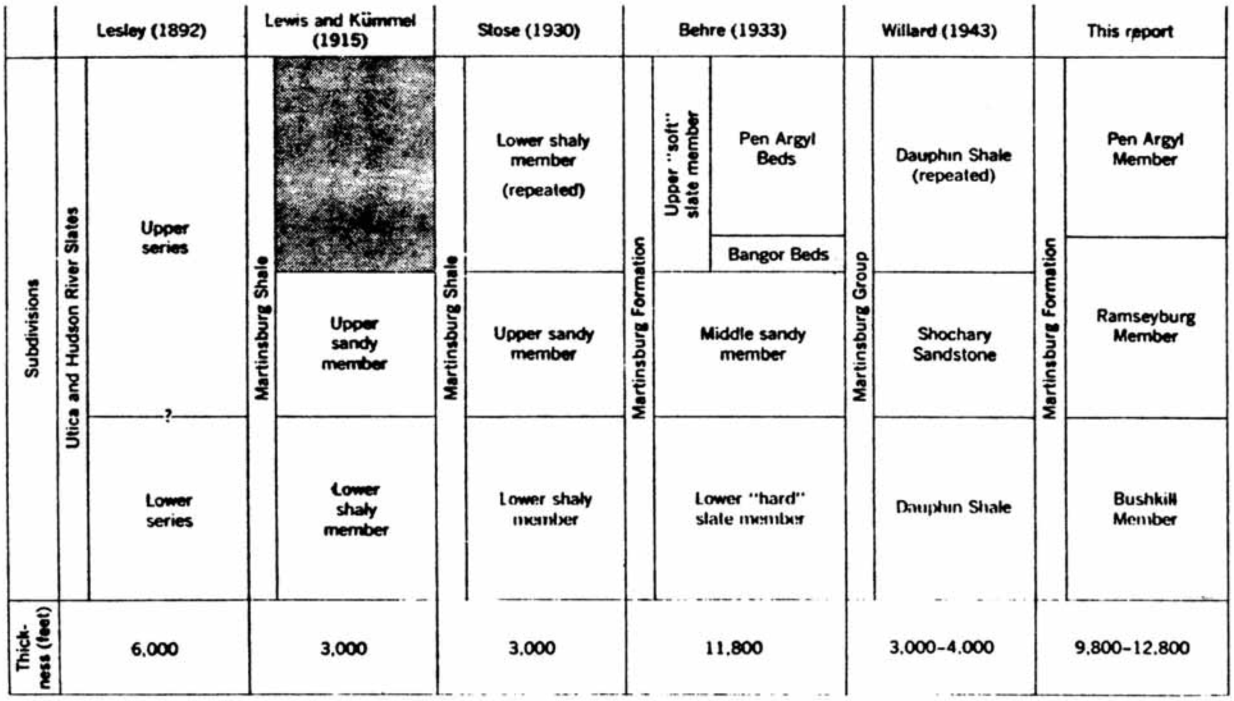
~~~~~~~~~~~~~~~~~~~~Surface of unconformity~~~~~~~~~~~~~~~~~~~~

[**Grenville orogeny**; deformation, metamorphism, and plutonism dated about 1,100 Ma. After the orogeny, an extensive period of uplift and erosion begins. Grenville-aged (Proterozoic Y) basement rocks include the Fordham Gneiss of Westchester County, the Bronx, and the subsurface of western Long Island (Queens and Brooklyn Sections, NYC Water Tunnel #3), the Hudson Highland-Reading Prong terrane, the Franklin Marble Belt and associated rocks, and the New Milford, Housatonic, Berkshire, and Green Mountain Massifs.]

~~~~~~~~~~~~~~~~~~~~Surface of unconformity~~~~~~~~~~~~~~~~~~~~

In New Jersey and Pennsylvania rocks older than the Franklin Marble Belt and associated rocks include the Losee Metamorphic Suite. Unconformably beneath the Losee, in Pennsylvania, Proterozoic X rocks of the Hexenkopf Complex crop out.

Table 03 - Comparative columns illustrating subdivisions of the Martinsburg Formation according to various authors. "This report" refers to Drake, A. A., and Epstein, J. B., 1967, The Martinsburg Formation (Middle and Upper Ordovician) in the Delaware Valley, Pennsylvania-New Jersey: United States Geological Survey Bulletin 1244-B, 16 p., their Figure 1, p. H4, from which this table was copied.

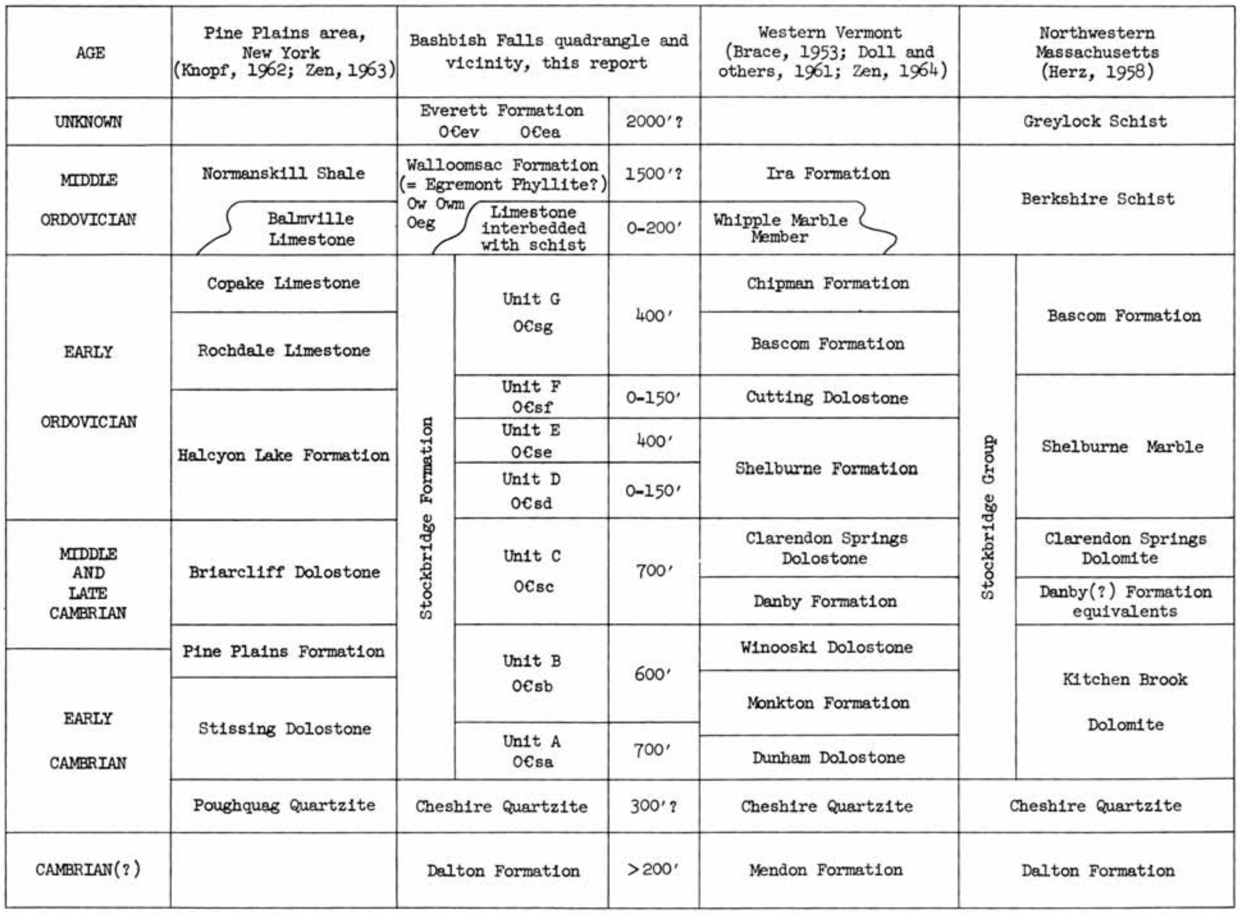


<table>
<tr><th></th><th colspan="2">Lesley (1892)</th><th colspan="2">Lewis and Kümmel (1915)</th><th colspan="2">Stose (1930)</th><th colspan="3">Behre (1933)</th><th colspan="2">Willard (1943)</th><th colspan="2">This report</th></tr>
<tr><td rowspan="4">Subdivisions</td><td rowspan="4">Utica and Hudson River Slates</td><td rowspan="3">Upper series</td><td rowspan="4">Martinsburg Shale</td><td rowspan="2"></td><td rowspan="4">Martinsburg Shale</td><td rowspan="2">Lower shaly member
(repeated)</td><td rowspan="4">Martinsburg Formation</td><td rowspan="2">Upper "soft" slate member</td><td>Pen Argyl Beds</td><td rowspan="4">Martinsburg Group</td><td rowspan="2">Dauphin Shale
(repeated)</td><td rowspan="4">Martinsburg Formation</td><td>Pen Argyl Member</td></tr>
<tr><td>Bangor Beds</td><td rowspan="2">Ramseyburg Member</td></tr>
<tr><td>Upper sandy member</td><td>Upper sandy member</td><td colspan="2">Middle sandy member</td><td>Shochary Sandstone</td></tr>
<tr><td>?
Lower series</td><td>Lower shaly member</td><td>Lower shaly member</td><td colspan="2">Lower "hard" slate member</td><td>Dauphin Shale</td><td>Bushkill Member</td></tr>
<tr><td>Thickness (feet)</td><td colspan="2">6,000</td><td colspan="2">3,000</td><td colspan="2">3,000</td><td colspan="3">11,800</td><td colspan="2">3,000-4,000</td><td colspan="2">9,800-12,800</td></tr>
</table>

Table 04 - Silurian and Devonian formations near Highland Mills, NY (Boucot, Gauri, and Southard, 1970)

Group	Formation (and Member)	Thickness (feet)
Stone Ridge Group	Bellvale Flags (=Hamilton)	
	Cornwall Shale (=Marcellus)	
	(covered)	
	Pine Hill Formation	
	Kanouse Member	25-150(?)
	Woodbury Creek Member	125
	Esopus Formation	
	Eddyville Member	80
	Highland Mills Member	155
	Quarry Hill Member	165 (max.)
	Mountainville Member	210-110
	Connelly Conglomerate (="Oriskany"?)	40-45
	Central Valley Sandstone	up to 50-60
	(covered)	
Helderberg Group	New Scotland Formation	60
	Kalkberg Limestone	50
	Coeymans Limestone	13
	Rondout Formation	25-40
	Decker Formation	25
	Poxono Island Formation	75
	Longwood Formation	160
	Mudstone member	95
	Sandstone-siltstone mbr.	65; 8-10
	Shawangunk Formation	
	Sandstone member:	
	Evenly bedded sandstone	13
	Cross-bedded sandstone	8
	Red sandstone	2-5
	Quartzitic sandstone	55
	Conglomeratic member	115 (W)-285 (E)

Table 05 - Chart showing correlation of Bashbish Falls quadrangle, New York and Massachusetts with adjacent areas. (From Zen and Hartshorn, 1966).



AGE	Pine Plains area, New York (Knopf, 1962; Zen, 1963)	Bashbish Falls quadrangle and vicinity, this report			Western Vermont (Brace, 1953; Doll and others, 1961; Zen, 1964)	Northwestern Massachusetts (Herz, 1958)	
UNKNOWN		Everett Formation OꞒev OꞒea		2000'?		Greylock Schist	
MIDDLE ORDOVICIAN	Normanskill Shale	Walloomsac Formation (= Egremont Phyllite?)		1500'?	Ira Formation	Berkshire Schist	
	Balmville Limestone	Ow Owm Oeg	Limestone interbedded with schist	0-200'	Whipple Marble Member		
EARLY ORDOVICIAN	Copake Limestone	Stockbridge Formation	Unit G OꞒsg	400'	Chipman Formation	Stockbridge Group	Bascom Formation
	Rochdale Limestone				Bascom Formation		
	Halcyon Lake Formation		Unit F OꞒsf	0-150'	Cutting Dolostone		Shelburne Marble
			Unit E OꞒse	400'	Shelburne Formation		
			Unit D OꞒsd	0-150'			
MIDDLE AND LATE CAMBRIAN	Briarcliff Dolostone		Unit C OꞒsc	700'	Clarendon Springs Dolostone		Clarendon Springs Dolomite
					Danby Formation		Danby(?) Formation equivalents
EARLY CAMBRIAN	Pine Plains Formation		Unit B OꞒsb	600'	Winooski Dolostone		Kitchen Brook Dolomite
	Stissing Dolostone				Monkton Formation		
			Unit A OꞒsa	700'	Dunham Dolostone		
	Poughquag Quartzite	Cheshire Quartzite		300'?	Cheshire Quartzite	Cheshire Quartzite	
CAMBRIAN(?)		Dalton Formation		>200'	Mendon Formation	Dalton Formation	

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