DUKE GEOLOGICAL LABORATORY

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TRIPS ON THE ROCKS

Guide 22: New Haven-East Haven-Branford Area, Connecticut

Trip 38A: 27 April 1996

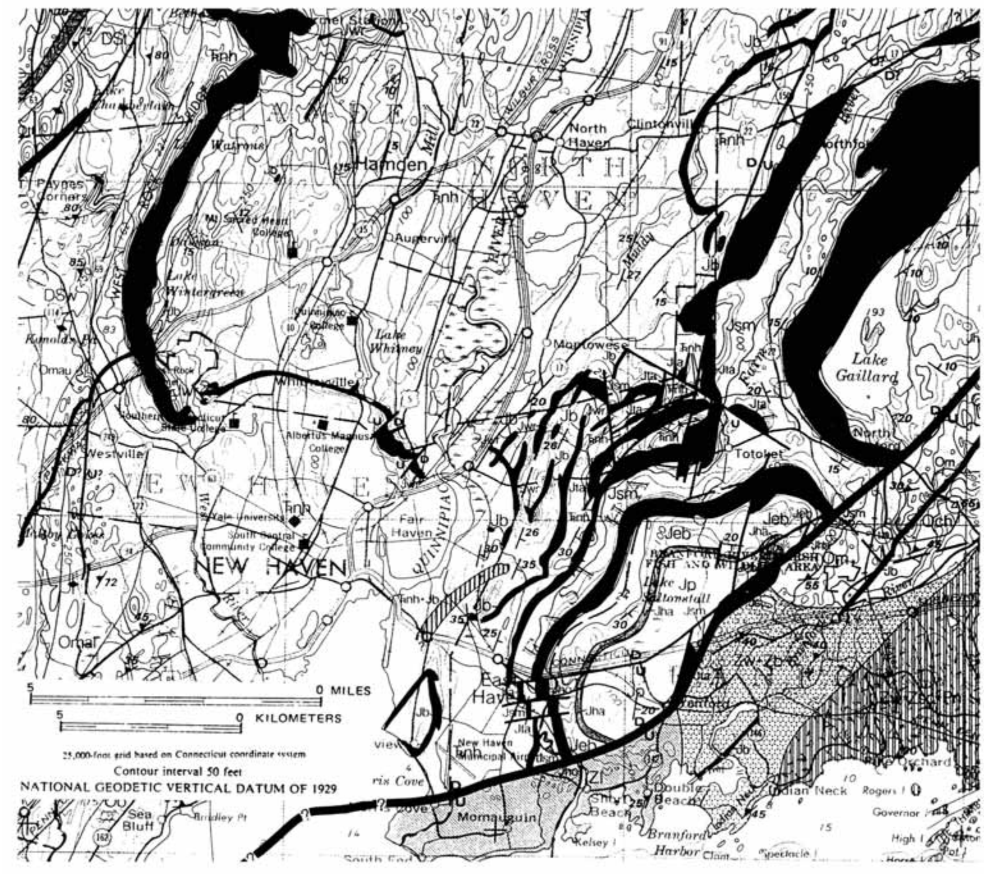

Figure 1. Geological map of New Haven, CT. (Rodgers, 1985.)

Field Trip Notes by:

Charles Merguerian and John E. Sanders

CONTENTS

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Guide 22: New Haven-East Haven-Branford Area, Connecticut

Trip 38A: 27 April 1996

Logistics:
Departure from NYAS: 0830
Return to NYAS: 1800
Bring lunch, including drinking water or other beverages.

INTRODUCTION

Today's trip to the New Haven area will provide an opportunity to study the geologic relationships at the south end of the Hartford Basin (Figure 1, on cover) for comparison with the situation at the NE end of the Newark Basin. We will start by examining the basal contact of the Newark Supergroup, something that is not possible to do in the Newark Basin. Other topics include the sedimentological characteristics of the thick basal formation, the New Haven Arkose (Figure 2), the contact-metamorphic effects on the New Haven Arkose of a dike, and the geologic relationships in the Gaillard graben, a fault block adjacent to the basin-marginal fault that was active during deposition, at least during the time when the two sedimentary formations between the three extrusive complexes accumulated. These sedimentary formations are the Shuttle Meadow Formation (between the basal Talcott extrusive complex and the median Holyoke complex, which is the thickest of the three) and the East Berlin Formation (between the Holyoke and the upper complex, the Hampden). We shall spend most of our time in the East Haven-Branford area, where coarse sedimentary rocks near the basin-marginal fault are interbedded with the extrusive sheets. Our itinerary will take us to Stony Creek to look at the pink granite and to Lighthouse Point for other granitic rocks, both of which provided much feldspar into the Newark Supergroup sediments in southern Connecticut. We will also examine the relationships between faults and gaps in monoclinal ridges underlain by sheets of extrusive igneous rock.

The area is one with which I am familiar from detailed mapping carried out more than 30 years ago and that I have revisited a few times since then. It is also a region that became a cause celebre between members of the geology faculty at Harvard and at Yale. At issue was the origin of the igneous rocks ("trap rocks") underlying the topographically prominent ridges, which had been so meticulously mapped by James Gates Percival (1842). Percival offered no interpretation of these sheets. Later, however, their origins became an important subject. Were these sheets intrusive? or extrusive?

The famous Yale Professor James Dwight Dana (1813-1895) examined the trap-rock bodies within walking distance of his house in central New Haven and pronounced them all to be of intrusive origin (Dana, 1871; 1883a; 1891a, b). He was correct. However, Dana extrapolated from these correct observations within the city limits of New Haven to all the ridges within the Central Lowlands province of Connecticut and concluded they, too, were all of intrusive origin.

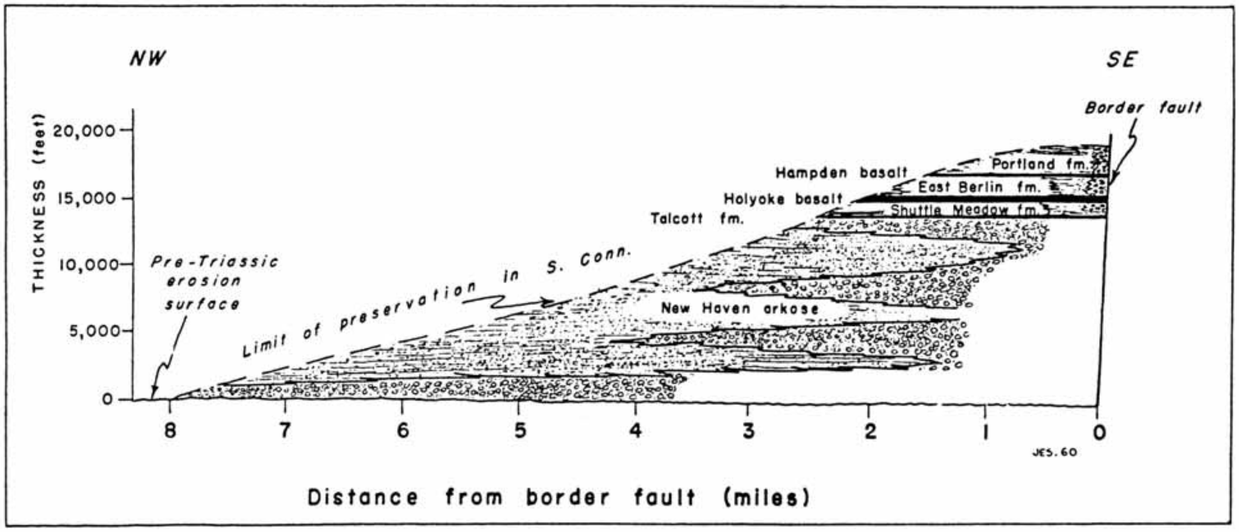


Figure 02. Restored stratigraphic diagram through Hartford basin-filling strata in southern Connecticut drawn on the supposition that all strata were initially horizontal and that present-day dip, which has been removed, is of postdepositional tectonic origin. (J. E. Sanders, 1960, fig. 2, p. 123.)

William Morris Davis (1850-1934), at that time a young instructor at Harvard, studied the relationships in central Connecticut, where he and his Harvard students proved that all the topographic ridges composed of "trap rock" are former lava flows, thus extrusives. After all is said and done, as the saying goes, more gets said than done. The upshot of this dispute is that Dana was correct with respect to what he had actually seen in New Haven and wrong with respect to his extrapolations outside of New Haven.

One of the side effects of Yale's embarrassment over the outcome of the Dana-Davis controversy was that the Yale faculty sees to it that every geology student is well versed in how to distiniguish a sill from an ancient lava flow (Figure 3). The barn door got locked after the horse had been stolen.

Apart from the question of who was right and who was wrong, tremendous implications were attached to the Davis extrusive interpretation. As Davis emphasized, extrusives are stratigraphic units that can be mapped just as if they were distinctive limestones, for example. Moreover, because the extrusion of a given lava flow can be considered as a geologically instantaneous process, the extrusive sheets serve as time markers. Not only that, but the lava spread across whatever kinds of sediments were on the ground at the time. For example, coarse gravels accumulated close to the basin-marginal fault, whereas mudstones were deposited in localities well away from this fault (Figure 4).

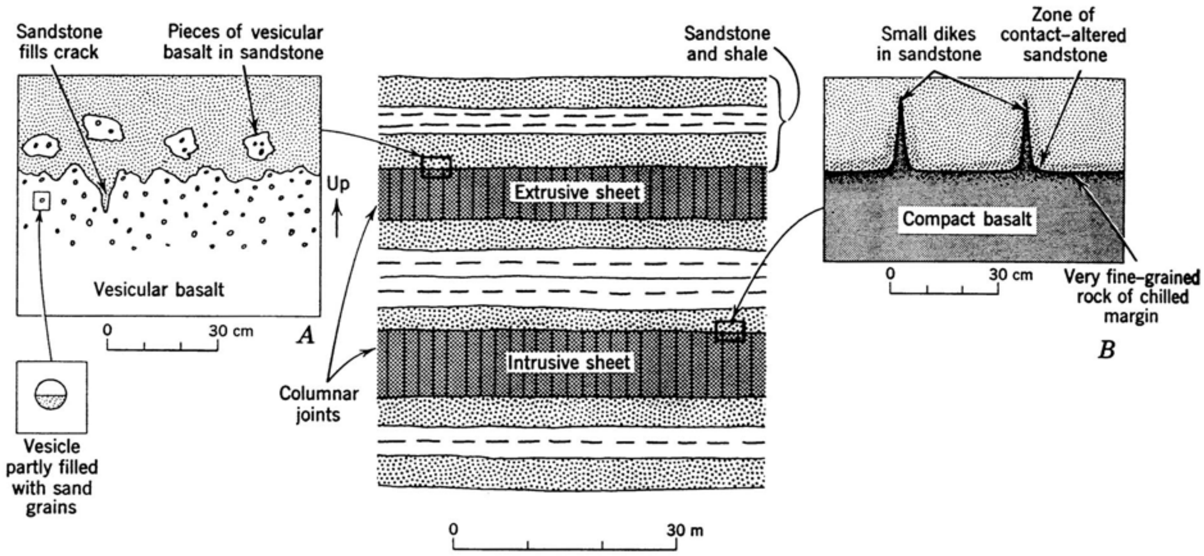


Figure 03. Geologic features for distinguishing a sill (intrusive sheet) from an ancient lava flow (extrusive sheet). (C. R. Longwell, R. F. Flint, and J. E. Sanders, 1969, fig. 20-6 and table 20-1, p. 494.)

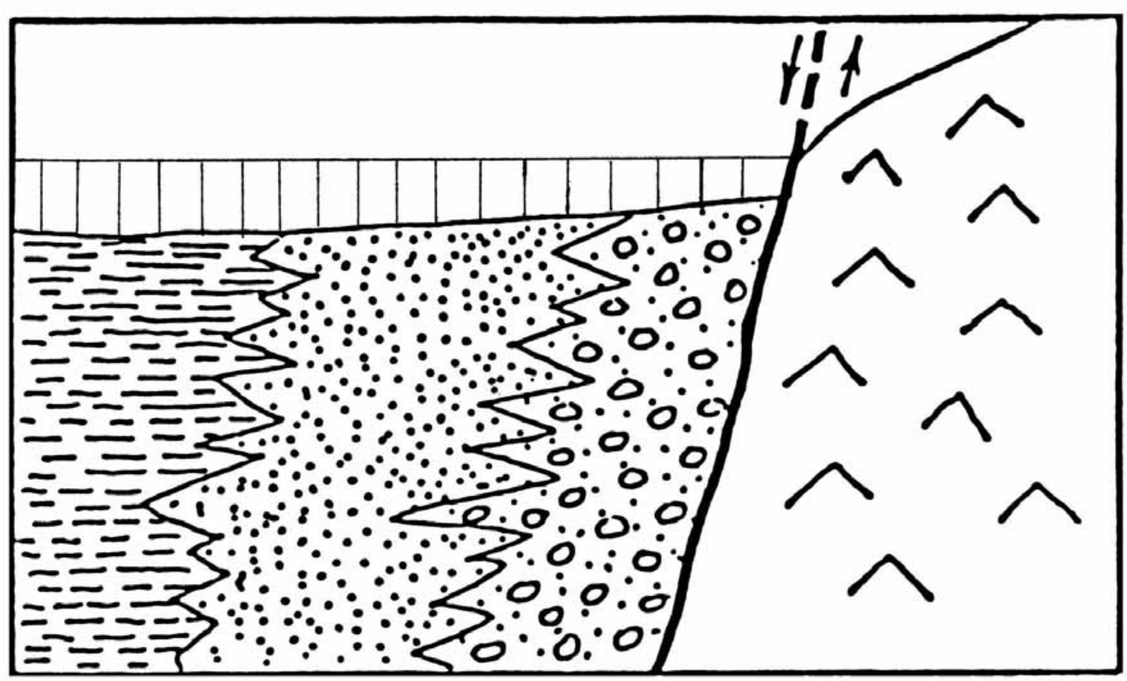


Figure 04. Schematic sketch of a sheet of extrusive igneous rock (vertical line pattern) from a former lava flow overlying gravel, sand, mud near margin of Hartford Basin. Notice how rudites adjacent to the basin-marginal fault give way to sands and then to silts/muds farther away from this fault. (After J. E. Sanders, 1968a, fig. 7A, p. 298.)

To assist you with the following discussion, consult Table 1 (a time chart showing geologic time subdivisions mentioned on the bedrock maps herein, with estimates of numbers of years for their boundaries and a list of some important local geologic events). I present a section on geologic background, a description of the geologic features of the New Haven area, and a discussion of how the geologic relationships established in the New Haven area bear on some currently cherished geologic dogma.

GEOLOGIC BACKGROUND

Under this heading, I include the generalized physiographic relationships, discuss the general features of the bedrock composing the terranes we shall visit, and conclude with a brief mention of the glacial deposits.

PHYSIOGRAPHIC RELATIONSHIPS

In today's trip, we will visit all three of the major physiographic provinces of Connecticut: (1) the Western Uplands, (2) the Central Lowlands, and (3) the Eastern Uplands (Figure 5). In general, the morphology matches the names of these provinces. That is, in the Uplands, the land levels attain altitudes of several hundred feet and low areas are mostly confined to modern river valleys. Within the generally low territory (underlain by sedimentary rocks) of the Central Lowlands, however, conspicuous linear ridges (underlain by igneous rocks) project as high or even higher as some parts of the Eastern- and Western Uplands. As we shall see, a close relationship exists between the physiographic aspect and the kinds of rocks.

GENERALIZED FEATURES OF BEDROCK IN TERRANES TO BE VISITED

In the following discussion, I emphasize the geology of our trip route only. I do not discuss details of the geology of the Eastern Uplands except in the context of correlation with the Western Uplands and as a parent area from which many of the sediments forming the filling of the Hartford Basin, which underlie the Central Lowlands, were derived.

As shown in Figure 5, each of the above-mentioned physiographic provinces is underlain by rocks that have been assigned to geologic terranes. For the most part, the Western Uplands are underlain by metamorphic- and igneous rocks, mostly of Paleozoic ages, that are designated by the number 3, which is labelled as the "Iapetos (Oceanic) Terrane." Without doubt, these rocks merit the designation "oceanic", but I question the wisdom of continuing to apply the "Iapetos" to these rocks. The term "Iapetos" (the father of Atlantis) is an outgrowth of the plate-tectonic concept that the Atlantic Ocean closed and then open up again. Users of this term presume that the rocks are now forming the eastern margin of North America have always formed the eastern margin of North America. However, early in the Paleozoic Era, North America straddled the Earth's Equator, and what is now the eastern margin was then the southern margin (Figure 6). If any paleo-ocean needs to be mentioned, then perhaps "Paleo-Tethys" is more appropriate.

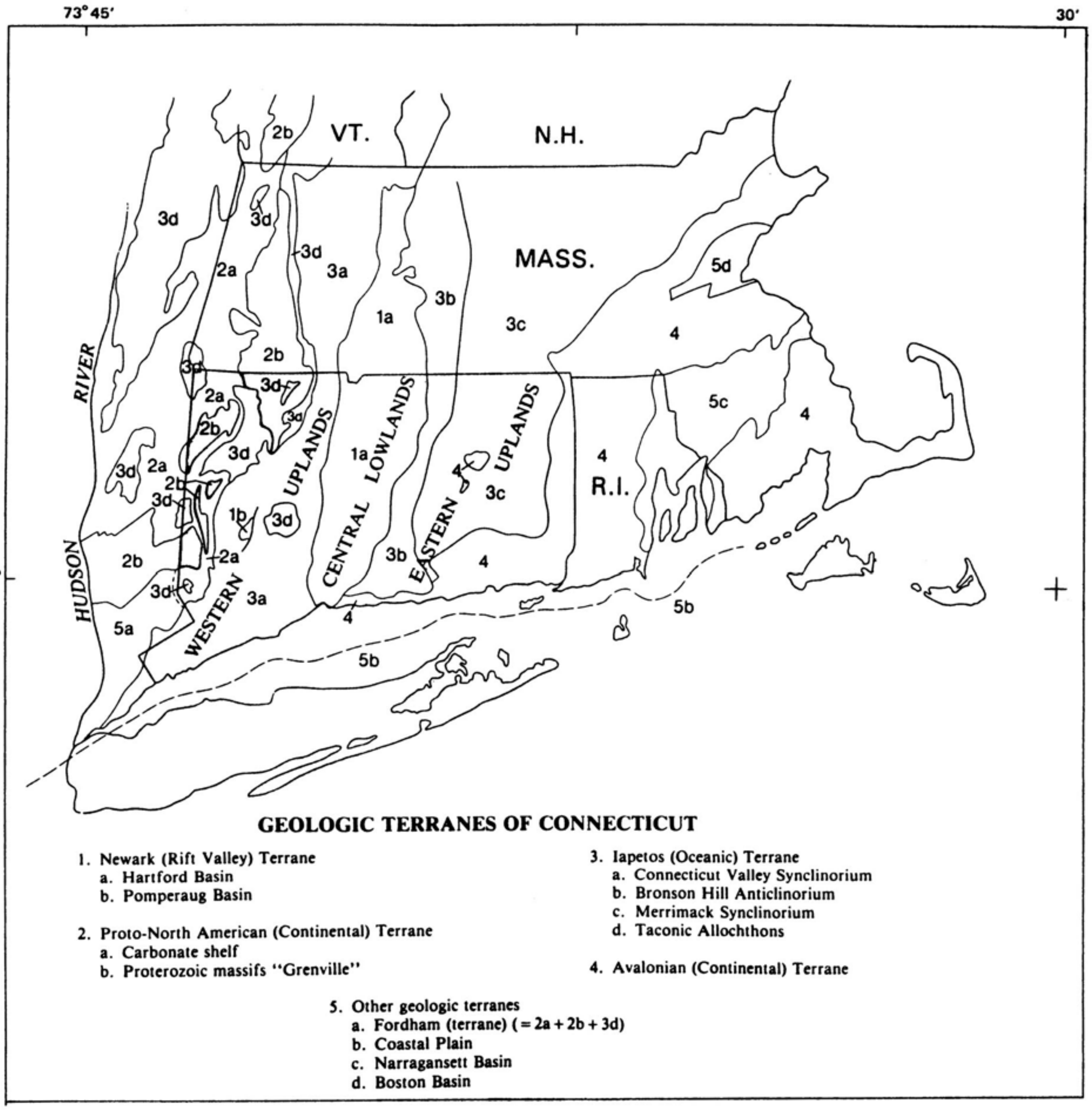


Figure 05. Index maps of physiographic provinces and geologic terranes in Connecticut and vicinity. (John Rodgers, 1985).

We will drive across the metamorphic rocks underlying the Western Upland and examine only its eastern part that forms the floor of the Hartford basin. Only two exceptions are known to the general statement that the Western Uplands are underlain by oceanic rocks, metamorphic and igneous. In these two exceptional areas, (1) the Pomperaug Valley, and (2) Cherry Brook valley, Canton Center, nonmarine sedimentary rocks are present (Platt, 1957). The sedimentary strata (and igneous rocks in the Pomperaug Valley) of these two areas are thought to have been continuous formerly with those of the Hartford Basin.

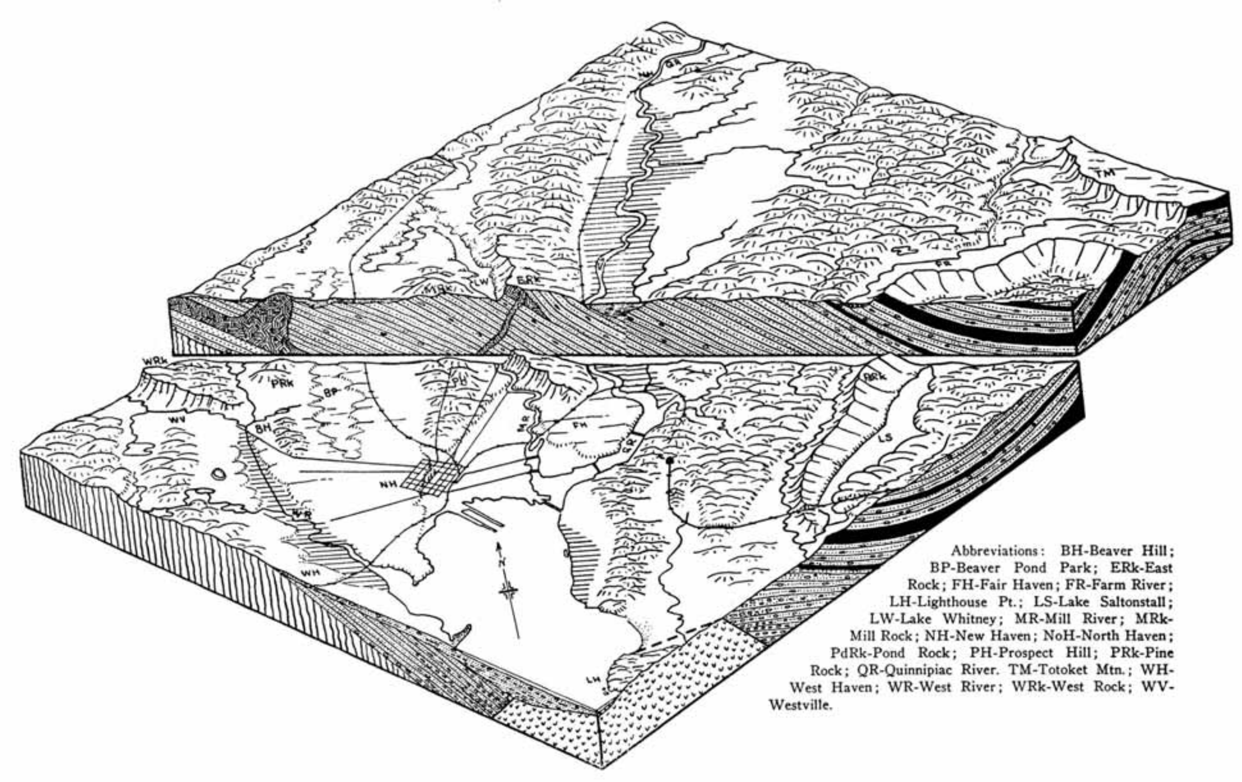


Figure 06. Block diagram of New Haven area viewed obliquely downward from above with three vertical panels cut away to show the geologic structural relationships. Ridge-making sheets of extrusive igneous rocks shown in black (at R, in East Haven-Branford area); ridge-making intrusives shown by "ropy" line pattern (the two "rocks" in New Haven, West Rock, at L, and East Rock, in center). (R. F. Flint, 1930, fig. 35, p. 178-179.)

At the point where we shall study them, the rocks of the Western Uplands consist of greenschists and altered volcanic rocks (Fritts, 1962, 1963a, 1965b; Burger, 1967). These rocks formed the floor of the Newark Basin which subsided and was buried by thousands of meters of nonmarine sedimentary strata and interbedded sheets of extrusive igneous rocks (the Newark Supergroup)

The rocks underlying the Central Lowlands are assigned to the "Newark (Rift Valley) Terrane in Figure 5. As I hope to convince you today, significant doubt can be raised about the continued used of "rift" with respect to the strata of the Newark Supergroup. Rift or no, these strata filled the subsiding Hartford basin. The tilted- and eroded edges of these strata now underlie the Central Lowlands. In this guidebook, I hope I succeed in keeping before the reader the difference between the Hartford basin, which was a tectonic basin that actively subsided during the Triassic- and Jurassic Periods, and the modern lowland (Central Lowlands of Connecticut), a low topographic region because the tilted- and eroded edges of the Hartford basin-filling strata are less resistant that the rocks of the neighboring uplands. From what many geologists have written, the reader comes away with the impression that the modern lowlands are synonymous with the early Mesozoic tectonic feature.

The eastern margin of the Hartford basin was formed by a large fault, comparable to the Ramapo fault of NW New Jersey, but so far in Connecticut, never given a formal geographic name. "The Great Triassic Fault" (W. L. Russell, 1922 ms.; 1922) or simply "Great Fault" are the terms usually applied. I shall use basin-marginal fault.

The rocks of the Eastern Uplands (Nos. 3 and 4 on the "terrane list" of Figure 5) are assigned to both the oceanic- and continental categories. The continental rocks are termed Avalonian. Notice that they are not labeled "proto-North American." We shall examine some of the Avalonian rocks, notably the Stony Creek Granite and associated feldspathic quartzites (Plainfield Formation) and granitic gneisses, and the Lighthouse Granite-gneiss.

Late in the Triassic- and early in the Jurassic Periods, the basin-marginal fault started its long career. Along it, rocks underlying the Eastern Uplands were elevated and eroded to provide sediment that was transported westward into the subsiding Hartford basin. The strata that filled this basin are assigned to the Newark Supergroup, of Late Triassic-Early Jurassic ages (Cornet and Traverse, 1975; Olsen, 1978, 1984 ms.; Olsen, McCune, and Thomson, 1982; Froelich and Olsen, 1985). Interstratified with the nonmarine sedimentary strata are the products of three episodes of mafic volcanism (Barrell, 1915; Longwell, 1933, 1937)

In general, a close relationship exists between clasts in the basin-margin sediments and parent areas in the bedrock of the Eastern Uplands. This situation forms the basis for the conclusion that no major strike-slip motion has taken place along the basin-marginal fault. One point of some interest is the presence in the basin-marginal coarse sediments of greenschist pebbles resembling the rocks of the basin floor that we shall see at Stop 1. Presumably such rocks formerly extended eastward far enough to have been part of the elevated block. Now, however, all that is left is the pebbles.

During at least part of the sediment-accumulation stage, along the SE side of the subsiding Hartford Basin, the Gaillard graben (Sanders, Guidotti, and Wilde, 1963) formed. In this graben the thicknesses of the Shuttle Meadow and East Berlin formations are up to 3 times greater than in areas outside this graben. Possibly similar thickness relationships prevailed during deposition of the New Haven Arkose and the Portland Formation, but comparisons of thicknesses of these units between southern Connecticut and central Connecticut are no longer possible. The thickness of the New Haven Arkose cannot be demonstrated in either southern Connecticut (where the outcrop belt is very wide) or in central Connecticut (where the outcrop is narrow but bounded on the W by a fault of not-known displacement). Only small remnants of the Portland Formation a few hundred meters thick are preserved in narrow outcrop belts in southern Connecticut compared with several kilometers or more in a very wide outcrop belt in central Connecticut.

The Hartford basin-filling strata dip regionally toward the east (compare with regional westward dip in the Newark basin). Because all the strata were initially deposited in horizontal positions, their modern-day dips must be ascribed to the effects of post-Early Jurassic, pre-Late Cretaceous tectonic uplift, with the axis of this feature located to the west of South Britain, Connecticut, where east-dipping Newark-age strata are exposed in the valley of the Pomperaug River.

REGIONAL GLACIAL FEATURES

The glacial deposits of Connecticut include the work of at least two ice sheets that flowed from contrasting directions: (i) from the NNE to the SSW, and (ii) from the NW to the SE, the same two directions previously discussed by Sanders and Merguerian in the New York City region (Sanders, 1974a; Sanders and Merguerian, 1991a, b; 1992; Merguerian and Sanders, 1992b, 1993a, b; 1994d). These two directions were noticed under the heading of "Diluvial Scratches" by the great genius of Connecticut geology, J. G. Percival (1842). Two tills having these contrasting directions of flow have been described from central Connecticut: the older, Lake Chamberlain Till with flow from NW to SE; and the younger, Hamden till, with flow from NNE to SSW (Flint, 1961). In addition, evidence for significant end moraines has been described along the Long Island Sound coast of Connecticut (Flint and Gebert, 1974 and 1976). I think these end moraines are the terminal moraines for the glacier that deposited the Hamden till, which I assign to the Woodfordian, the latest glacial advance in the Wisconsinan Stage.

Drumlins having long axes oriented NW-SE are abundant as are drumlins having long axes oriented NNE-SSW. The coexistence of such drumlins inferred to have been the work of two different ice sheets is hard for some glacial geologists to accept. They argue that the younger glacier should have wiped out all traces of any older glacier, especially one having a contrasting flow direction (Flint, 1943, 1951). JES has no simple explanation for how this can have happened; he merely cites the topographic maps as proof that it did happen.

The main interest in the glacial geology of Connecticut has centered around the aboundant evidence left behind when the last glacier melted. Connecticut's deglacial history contrasts decidedly with that of the midwestern United States, which had been studied first and therefore had been taken as a standard for reference. In the midwestern states, the outer margin of the last glacier retreated northward while the ice mass remained a glacier. That is, it was continuing to flow outward from its center(s) of accumulation, but this rate of outflow was exceeded by the rate of melting of the margin. Accordingly, the retreating glacier left behind a great series of end moraines (also known as recessional moraines). Each of these was heaped up as the ice halted, or even advanced slightly during the general retreat. In Connecticut, however, Flint (1930) demonstrated that the hallmark of the disappearance of the last ice was extensive deposits from meltwater, many of which formed in contact with blocks of stagnant ice. The interpretation is that the former glacier underwent a general meltdown and became so thin that its gravity-driven outflow ceased. No series of recessional moraines resulted. Instead, lake deposits are numerous and outwash sand and -gravel blanket the countryside.

GEOLOGIC SUMMARY OF NEW HAVEN AREA

In this section, I discuss the physiographic features of New Haven and vicinity, the stratigraphy of the Newark Supergroup, paleogeographic relationships (including primary sedimentary structures), the geologic structure, the glacial features, and the drainage history.

PHYSIOGRAPHIC FEATURES OF NEW HAVEN AND VICINITY

New Haven (Figure 6) lies at the south end of the Hartford Basin, which coincides with the Central Lowlands province of Connecticut. Much of New Haven is underlain by a thick body of outwash sediments that was deposited as the Woodfordian glacier melted away. Today, the main drainage routes into New Haven Harbor are the Quinnipiac River on the E, and the Mill River and West River to the W (Figure 7). Farther E, is the Farm River, which now drains directly into Long Island Sound, but during the Pleistocene, emptied into New Haven Harbor at Morris Cove.

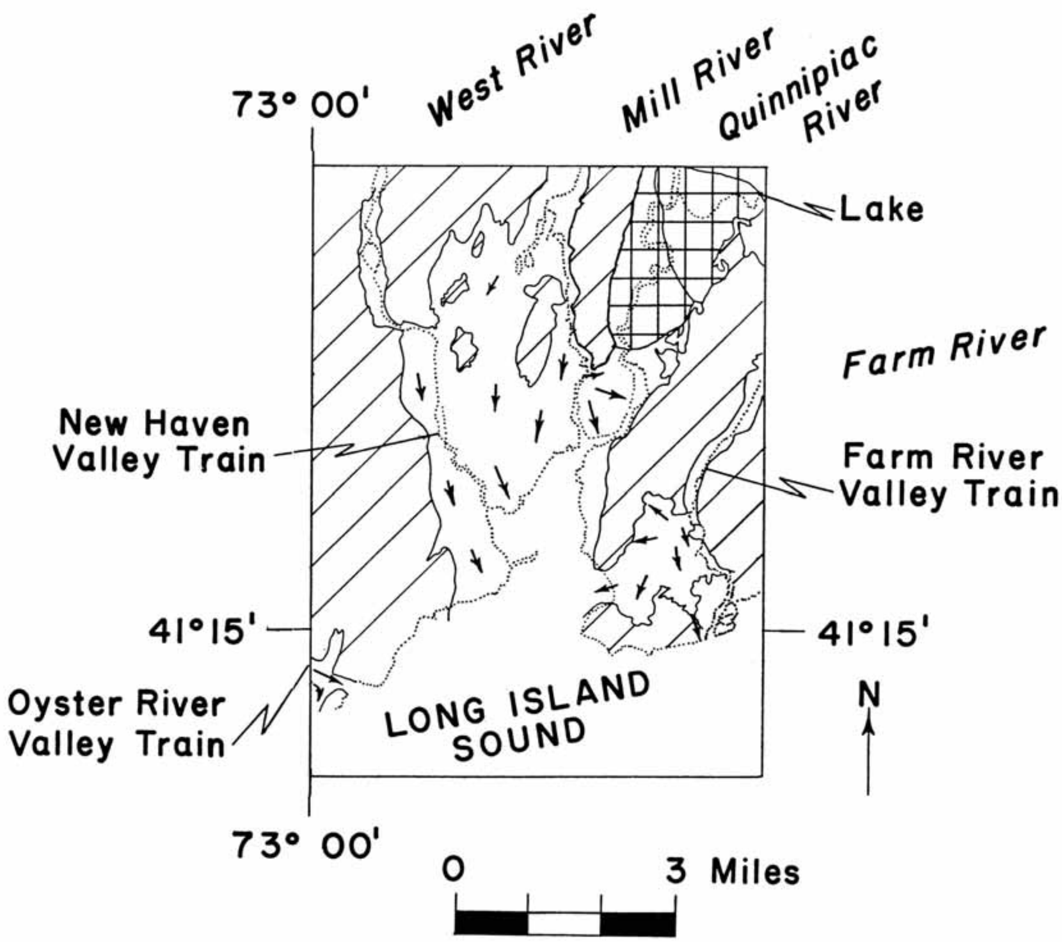


Figure 07. Map of modern rivers and Pleistocene outwash valley trains (composed of sand and silt) in New Haven area and their locations with respect to the proglacial lake in the southern Quinnipiac Valley. (J. E. Sanders, 1989 ms., based on mapping by R. F. Flint.

Two prominent "rocks," West Rock and East Rock, are underlain by concordant plutons composed of sheets of mafic igneous rock. West Rock is analogous to the Palisades. Mill Rock and Pine Rock, which extend between West Rock and East Rock, are discordant sheets (dikes) of mafic igneous rock of which no analogues are known in the Newark basin.

Under the water of New Haven harbor, I infer that the rocks of the Eastern Uplands are in fault contact those of the Western Uplands. A buried valley having a V-shaped transverse profile and talweg more than 950 feet below modern sea level extends WSW from New Haven harbor following the trend of this fault (Figures 8 and 9).

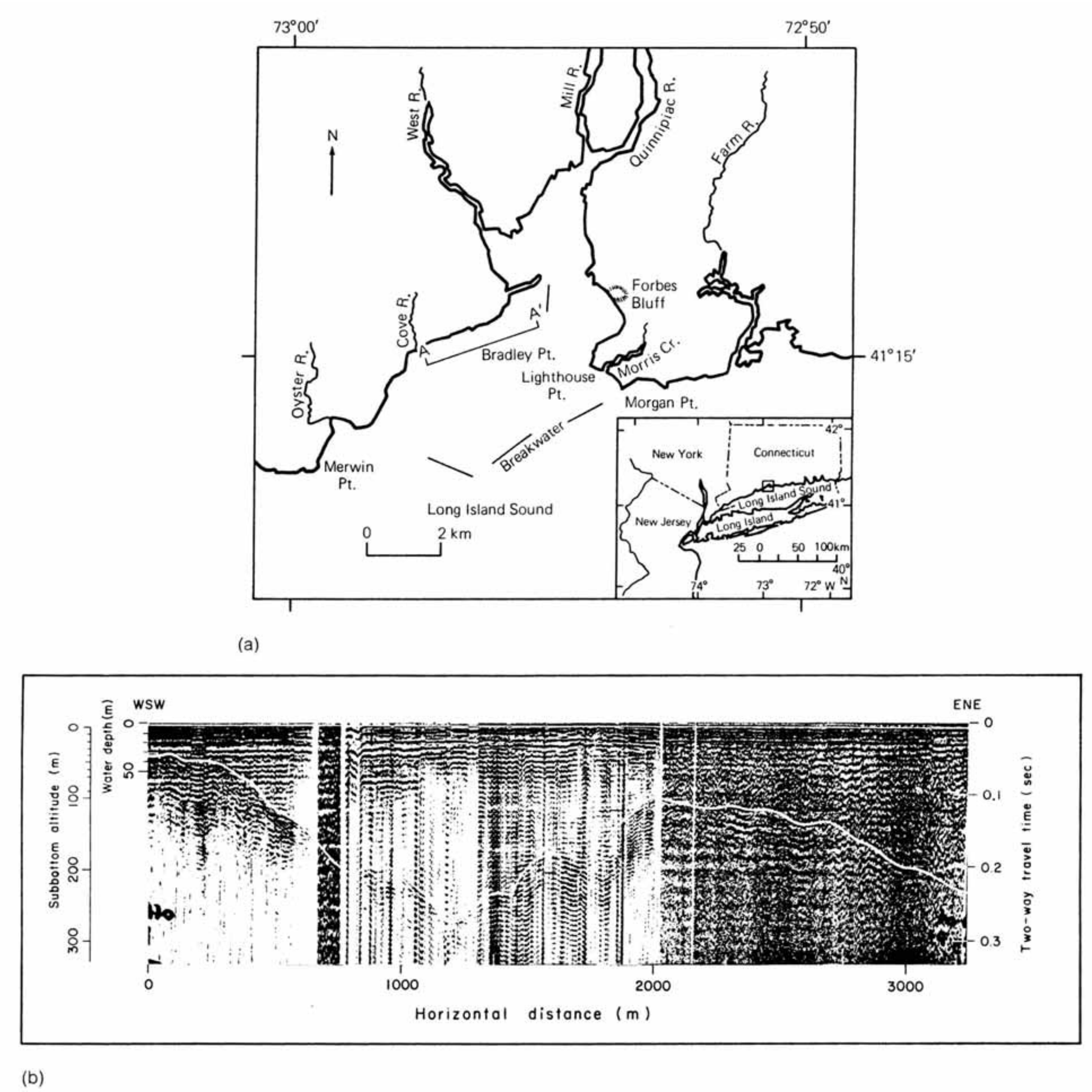


Figure 08. Buried valley, New Haven harbor, CT. (J. E. Sanders, 1981, fig. 19.12 (a) and (b), p. 486.)
A. Location map. Line AA' locates continuous seismic-reflection profile of Figure 08B.
B. Continuous-seismic-reflection profile along line AA' parallel to shore off West Haven, CT, showing V-shaped valley, eroded in metamorphic bedrock, with talweg extending to about -300 m (modern SL reference).

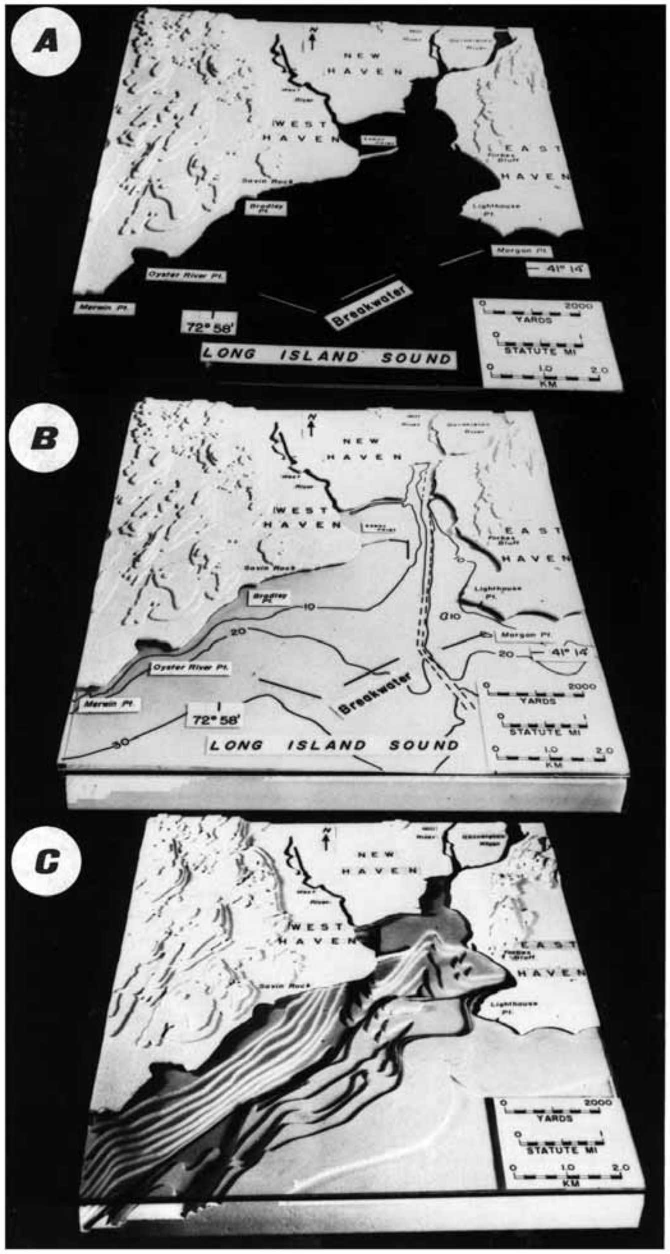


Figure 09. Photographs of styrofoam model of New Haven harbor and vicinity showing contrast between modern relief and buried valleys. (Model built by Topofoam, Inc., New York City, supported by U. S. Office of Naval Research at Hudson Laboratories of Columbia University, Dobbs Ferry, New York.)

A. View showing relief of the land (based on contours from U. S. Geological Survey), with each step representing 50 feet, and the first 50 feet taken up at the shoreline.

B. View with modern water depths shown by 10-foot isobaths (datum, mean sea level).

C. View showing shape of bedrock walls of buried valleys; each step equals 100 feet. The valley was arbitrarily ended in inner New Haven harbor where thick Holocene silt absorbed sound signals so that no reflections were returned from the top of the bedrock. (J. E. Sanders, 1981, fig. 19.13c, p. 487.)

Lying east of the Farm River Valley is a narrow belt of territory displaying a valley-and-ridge-type aspect. The ridges are underlain by tilted sheets of extrusive igneous rock and the valleys, by sedimentary strata. The most prominent of these ridges is Saltonstall Ridge. In the adjacent valley on the E side of Saltstonstall Ridge is a lowland mostly occupied by Lake Saltonstall, a water-supply reservoir.

STRATIGRAPHY OF NEWARK SUPERGROUP

NAME and GEOLOGIC AGE

The name Newark, from Newark, New Jersey, is a venerable one in American stratigraphy; it was proposed by W. C. Redfield in 1856. Today, the term Newark has been accorded the status of a Supergroup (Cornet, 1977 ms.; Olsen, 1980c, Froelich and Olsen, 1985; Luttrell, 1989).

The age range assigned to the strata composing the Newark Supergroup has oscillated back and forth like a geological pendulum. During the 19th century, based on studies of fossil fish, Redfield (1851, 1856, 1857) assigned them to the Jurassic. By contrast, dinosaur remains and -footprints suggested Late Triassic. Given this situation, some geologists classified these strata as Jura-Trias (for instance, Darton, 1902 in the New York City Folio 83 of the U. S. Geological Survey). Many geologists, however, took the Newark strata to be synonymous with Triassic (Cook, 1968, 1879, 1882, 1887, 1888, 1889).

But compulsive geologists who were inclined toward tidiness in classification were uncomfortable with the notion that a well-behaved formation should span the boundary between two geologic periods. Accordingly, when Pirsson and Schuchert (in their Textbook of Geology published in 1915) proposed the name "Palisades Disturbance" for the episode of crustal unrest which they supposed marked the end of the Triassic Period, they decided that, by definition, all the Newark strata had to be of Late Triassic age (i. e., they had been affected by the period-ending "Palisades Disturbance"). Thus, they started a line of thought that lasted for 60 years. In addition, they also started a tradition that might be expressed by the title of a modern book: "We learned it all in kindergarten." In this analogy, "we" is all geologists trained in the United States, "kindergarten" is the first-year college course in geology, and "learned it all" refers to knowledge about the Newark strata. Based on the Pirsson-Schuchert scheme of things, Widmer (1964, p. 85) wrote: "There are no known Jurassic sediments in eastern North America."

Modern students (Cornet and Traverse, 1975; McDonald, 1975 ms., 1982, 1992; Cornet, 1977 ms.; Olsen, 1978, 1980a, 1980b, 1984 ms.; Olsen, McCune, and Thomson, 1982; Olsen and McCune, 1991; Fowell and Olsen, 1993) have re-established what the real old-timers knew all along: the age range of the Newark strata is Late Triassic through Early Jurassic. (For a general summary of the geologic literature on the Newark Group up to 1984, see Margolis, Robinson, and Schafer, 1986.)

The names of the formations of the Newark Supergroup (with thicknesses in the Watchung syncline) are (Olsen, 1980b):

Formation Name	Thickness (m)
Boonton (sedimentary strata; top eroded)	500+
Hook Mountain Basalt (two flow units)	110
Towaco Formation (sedimentary strata)	340
Preakness Basalt (2, poss. 3 flow units)	300
Feltville Formation (sedimentary strata)	170
Orange Mountain Basalt (at least 2 flow	
units, one of them pillowed)	150
Passaic Formation	6,000
Lockatong Formation	150
Stockton Formation	350
Total (Watchung syncline)	**8,070+**

Where the three well-known sheets of extrusive basalt (Percival's "Anterior," "Main," and "Posterior" trap sheets, later named Talcott, Holyoke, and Hampden, respectively) are present, the Newark sedimentary strata are easy to subdivide. But where one is faced with an isolated exposure of a non-fossiliferous Newark-type reddish-brown sandstone, -siltstone, or -shale, or even a coarse conglomerate with reddish-brown sandstone matrix, the problem of assigning the correct formation verges on hopeless. Ultimately, some mineralogic- or lithologic criteria may prove to be helpful for stratigraphic assignment.

New Haven Arkose

The New Haven Arkose was named by Krynine (1941, p. 1919; 1950, p. 30, and table 1) for that part of Percival's (1842) Western Sandstone which underlies the lowest extrusive sheet.

On the basis of abundant schist pebbles in the lower part and their relative absence in the upper part, Krynine (1950, table 2, and p. 43-49) recognized lower- and upper members of the New Haven Arkose. In the Mt. Carmel quadrangle, Fritts (1963a) mapped a similar subdivision.

No type section was ever designated for the New Haven Arkose; indeed, no continuous section suitable for this purpose has yet been found. Scattered exposures in the Quinnipiac lowland near New Haven, however, reveal the general characteristics of this formation. Its thickness has never been satisfactorily determined.

One of the most-prominent and -continuous exposures is located in the north-central part of the Branford quadrangle, in SW North Haven just NW of the extreme northern end of East Haven, along the NE face of the elongate hill that lies N of Half Mile Road, west of Clintonville Road, and southeast of Middletown Avenue (Connecticut Route 17), approximately 2 mi. NE of Rabbit Rock (19.12N, 57.78E to 19.44N, 57.80E). Another excellent section is exposed in the deep cuts along the abandoned trolley line where the road bridge crosses over the old trolley right-of-way, at the SE end of Old Russo Avenue, Foxon (17.52N, 57.06E). A small sill is present at the W end of the S face, but otherwise, the cut exposes New Haven pebbly arkose for nearly 200 ft horizontally. Other exposures are abundant in the bluffs E of Quinnipiac Avenue in the extreme NE part of New Haven (17.80N, 56.600E to 18.50N, 56.96E). The cuts along Route 80 (Foxon Road) opposite the entrance to the abandoned Foxon Trap Rock Company quarry 0.15 mi. W of the New Haven-East Haven town line (17.74N, 56.68E) display typical varieties of New Haven Arkose, including the contact-metamorphosed sandstones.

The New Haven Arkose consists of complexly interbedded units of thick-bedded, coarse-textured, conglomeratic sandstones, commonly devoid of internal structure but locally vaguely laminated or cross stratified, together with structureless maroon pebbly- to sandy siltstones that are extremely poorly sorted. Both kinds contain the same varieties of coarse constituents: pebbles and boulders of Plainfield Quartzite, pegmatitic pink feldspar, granites and granitic gneisses, muscovite, and locally, two-mica schists, green schists, and phyllites. As mentioned, Krynine's proposed twofold subdivision of the New Haven Arkose was based on abundant schist pebbles in the lower unit, and less-abundant schist pebbles in the upper unit. Krynine supposed that the Stony Creek Granite is a stock and that its gradual unroofing caused this change in composition of the New Haven Arkose. According to Krynine's concept, as the stock became unroofed, plutonic material would gradually supplant the metamorphic material in the sedimentary debris supplied to the Hartford basin. In his work on the adjoining Mount Carmel quadrangle, Fritts (1963) accepted Krynine's subdivision. I have observed abundant schist pebbles in units overlying the New Haven Arkose. Accordingly, I doubt the validity of the concept that the abundance of schist pebbles declined with time and thus reject Krynine's proposed subdivision of the New Haven Arkose.

Talcott Formation

The Talcott Formation was named by B. K. Emerson (1898a, p. 6) from the town of Talcott, Connecticut, which is located in the northwestern part of the outcrop belt of the Newark Supergroup. The Talcott Formation includes Percival's (1842) Anterior Trap Sheet and the lower extrusive sheet ("lava flow") of most other authors.

I have been able to recognize a sevenfold subdivision of what had been regarded previously as one unit designated as basalt.

The Talcott Formation crops out in six discontinuous belts. Of these, belts 1 to 3 lie west of the more-prominent ridges underlain by the Holyoke Formation. Belts 4 to 6 lie along the basin-marginal fault in the Branford quadrangle, east of Saltonstall Ridge (underlain by the Holyoke Formation).

Previous workers in the area have assigned the volcanic rocks in belts 5 and 6 to the "upper lava flow" (Hampden Formation of current usage). As is explained in following sections, my new stratigraphic information indicates that the rocks in these two belts clearly belong instead to the Talcott Formation.

Previously published maps and reports (Percival, 1842; Hovey, 1889; Davis, 1898, map and also p. 98; Longwell, 1932, 1933; Krynine, 1950) show belt 2 of the Talcott Formation ending abruptly north of the Amtrak railway line in East Haven. In contrast, I have confirmed the unpublished observations of George Beck (1907-1909 ms.) that this belt of the Talcott Formation extends south to the basin-marginal fault west of Beacon Hill.

I ascribe the absence of the Talcott Formation between belts 1 and 2 to a fault, which I infer has dropped the overlying Shuttle Meadow Formation against the underlying New Haven Arkose.

The basalt members of the Talcott Formation tend to form ridges, whereas the intervening sandstone units tend to form strike valleys. As a result of complex faulting, this valley-and-ridge aspect of the Talcott Formation is not commonly seen. A particularly fine example of it, however, is located in Foxon (northern East Haven), just north of Route 80, from Deer Run School eastward for nearly 0.5 mi.

According to my interpretation, the Pleistocene deposits in the Farm River valley in the Branford quadrangle obscure the upper two thirds of the Talcott Formation and this part of the unit does not crop out south of Foxon.

Excellent exposures of parts of the Talcott Formation are in the cuts on the Connecticut Turnpike: in East Haven west of Saltonstall Ridge; and in Branford near the Todds Hill Road overpass, just west of Interchange 54, Branford quadrangle. Other fresh exposures are in the Branford quadrangle: in cuts on Route 80, Foxon; in the abandoned Dixwell quarry (on Thompson Street near the corner of Thomaston Street, in northern East Haven); and along Clintonville Road and Idlewood Drive, a street that extends eastward from Village Street north of its junction with Totoket Road, North Branford. In addition, natural exposures, too numerous to list individually, are present in the area that extends from Foxon northeastwrd to a point northeast of Northford (Wallingford quadrangle). The best place to observe the sequence of the lower five members is in the parallel ridges and intervening strike valleys that trend east west and are north of Route 80 between Foxon Pond and Deer Run School and eastward for approximately half a mile (Branford quadrangle).

From base upward, I designate the four basaltic members and three intervening sedimentary members informally as: basal brecciated flow, lower sandstone, lower massive flow, middle sandstone, brecciated-and-pillowed flow, upper sedimentary, and upper breccia members.

The thickness of the Talcott Formation in the Branford quadrangle is 1,000 ft. This figure is four to five times greater than thickness figures previously reported for the Talcott. The increase is based on my recognition of members not heretofore identified. Davis (1898, p. 62-63) observed what I consider to be the upper three members. Although his sequence was: compact basalt, sandstone, and "ash bed with blocks of lava and crystalline rocks," he mapped them all as a single unit, although locally, he did map the "ash bed" separately. Percival (1842, p. 326-327) remarked on the double-ridge characteristics of the Anterior Trap Sheet in the Foxon area.

Basal Brecciated Flow Member

The basal brecciated flow member is 150 feet thick. The basalt of this member generally is massive, but may be amygdaloidal and locally contains flow breccia. In this member, I have found fracture- and cavity fillings from that contain quartz, calcite, and other secondary minerals, but I have never seen pillows within it.

Lower Sandstone Member

The lower sandstone member rarely is well exposed. The sandstone from this member is identical to the coarser-textured varieties of the New Haven Arkose and in isolated exposures, cannot be distinguished from the New Haven. My thickness estimate of 40 ft. has been determined from drawing profile-sections from map data of positions of contacts.

Lower Massive Flow Member

The lower massive flow member is 100 ft. thick and as far as I have been able to determine, consists of massive basalt that lacks breccia. Locally, this member displays well-developed columnar joints. The lower massive flow member underlies the line of knolls east of Rabbit Rock.

Middle Sandstone Member

The middle sandstone member is at least 60 ft. thick. It is best exposed along the cuts of the abandoned trolley line W of Route 100 and NE of Maloney's Brook, East Haven (17.65N, 57.25E; Branford quadrangle). The sandstone is generally coarse textured and contains abundant pebbles. This member is also present along the western slope of the low ridge (locally known as Mullins Hill) that lies west of Saltonstall Ridge. Specimens of the middle sandstone member collected from the old Dixwell quarry show abundant pebbles of pegmatite with pink feldspar, pieces of pink feldspar, granite with both pink- and white feldspar, quartzite, smoky quartz, green schist and/or -phyllite, mica schist, and hornblende gneiss.

Brecciated and Pillowed Flow Member

The brecciated-and-pillowed flow member actually consists of two flow units separated by a few inches of sedimentary material. Where exposed in the cuts on the Connecticut Turnpike W of Saltonstall Ridge, East Haven (16.42 N, 56.67 E, Branford quadrangle), the lower flow unit is 60 ft. thick, and the upper flow unit, at least 50 ft. thick--possibly more. Profile-sections drawn from map data in the Foxon area suggest that the thickness of this member is 200 ft., of which 140 ft. belong to the upper flow unit.

The brecciated-and-pillowed flow member is more resistant morphologiically than are other members of the Talcott Formation. Accordingly, it is the unit that previous workers have regarded as the "lower lava flow." Apart from the flow breccia and pillows, this member is also displays distinctive cavities, some having shapes of crystals, that have been lined or filled with secondary minerals (LaGanza, 1960); and by a distinctive breccia named "ball-in-socket" breccia by W. L. Russell (1922 ms.). Russell thought that this breccia had resulted from tectonic activity along the basin-marginal fault, but the fact that the matrix of this breccia consists of fine-textured sedimentary material leads me to prefer the interpretation that the brecciation took place at time of extrusion.

The exposure of the brecciated-and-pillowed flow member along the south side of the Connecticut Turnpke, just west of the Todds Hill overpass, shows basaltic lava-flow units and two layers of interbedded sedimentary rock. I infer that these two sedimentary layers do not indicate a normal stratigraphic succession but rather are the same, single sedimentary unit repeated by faulting along an irregular fault that extends along the face of the steep exposure parallel to the highway.

Upper Sedimentary Member

The upper sedimentary member consists of a lower coarse-textured sandstone and an upper finer-textured siltstone- and carbonate-rock unit. The thickness of the member is 250 ft. Given more-numerous exposures, it would have been possible to map these two units separately. The upper part of this member is well exposed in the cut along the north side of the Connecticut Turnpike just west of the Todds Hill Road overpass (Branford quadrangle). Here, it consists of fine-textured maroon shaly siltstone. I found the carbonate rocks in the exposure east of Barberry Road and just west of the East Haven-North Branford Town Line, in the extreme northern part of East Haven (Branford quadrangle). These same exposures display the full thickness of this member and reveal both the lower sandstone and the upper fine-textured strata.

Upper Breccia Member

Although previous workers have noticed the rocks that I assign to the upper breccia member, these workers did not realize the lateral persistence and stratigraphic importance of the distinctive breccias. For example, Percival (1842, p. 316, 341-344) referred to these rocks as the "trap conglomerate." Davis (1898, p. 62-63) called them "tuffaceous trap" or the "ash bed." W. L. Russell (1922 ms.) also referred to this member as the "ash bed," but, as mentioned, assigned the rocks exposed near the basin-marginal fault northwest of Branford to the uppermost lava-flow unit (now the Hampden Formation) and supposed that the brecciation had resulted from faulting. Longwell (1922) identified this member as volcanic agglomerate and inferred that liquid lava on its way to the surface had picked up foreign rock fragments. The thickness of the upper breccia member is 200 ft.

The upper breccia member is well exposed in cuts on the north side of the Connecticut Turnpike just west of and underneath the bridge for the Todds Hill Road overpass (Branford quadrangle). The basal contact is well exposed striking N75°E and dipping 5 to 10° N. Small faults cut the rocks here, but nevertheless the stratigraphic relationships are clear. In the top few feet of siltstone below the basal contact, a few detached basalt blebs have been altered to light gray. In the basal layers of this member, rounded- and angular fragments of basalt are set in a matrix of maroon siltstone. A large sandstone "erratic" measuring 8 by 3 ft. on the exposed surface, is situated 10 to 15 ft. above the basal contact. A small fault striking N55°W and dipping 80°SW displaces this block of sandstone. Angular chunks of basalt are set in a matrix of particles of quartz and feldspar that also includes larger fragments of metamorphic rocks.

Shuttle Meadow Formation

The Shuttle Meadow Formation was named by Lehmann (1959, p. 7) for the beds that Krynine (1950, tables 1, 2, p. 31, 32) had designated as the Lower Sedimentary division of the Meriden formation. Percival (1842) considered these beds to be part of the Middle Shale in central- and northern parts of the Connecticut Valley area. Davis (1898) referred to these beds as the Anterior Shales.

The type locality of the Shuttle Meadow Formation, which exposes only its lower strata, is located in the New Britain qudrangle along the south shore of the Shuttle Meadow reservoir between Meriden and New Britain (Simpson, 1966). Because of their topographic weakness and the cover of glacial deposits, exposures of this unit are few and scattered. In the Meriden quadrangle (Hanshaw, 1968) and in the Middletown quadrangle (Lehmann, 1959, p. 11), the thickness of the Shuttle Meadow Formation is 310 feet. But, in the Branford quadrangle, the thickness of this formation is 900 feet.

As mentioned, the Shuttle Meadow Formation is rarely exposed. It is totally concealed beneath the Pleistocene sediments of the Farm River valley. The topmost strata are exposed locally along the western slopes of Totoket Mountain, Saltonstall Ridge, and Beacon Hill.

Where it consists of fine-textured materials, the Shuttle Meadow Formation is topographically weak and forms strike valleys. By contrast, near the basin-marginal fault, where it consists of conglomerate, it forms strike ridges.

Southward along the Farm River outcrop belt, as one approaches the basin-marginal fault, coarse conglomerates become interbedded with the fine-textured sandstones and -siltstones. A noteworthy feature of the clasts in these conglomerates is a gray, fine-textured limestone not observed at any other locality. The parent area from which these limestones were eroded is not known.

Holyoke Formation

The name Holyoke for a part of the Newark strata was proposed by B. K. Emerson (1898a) for a unit, which he designated as a basalt, that underlies the Holyoke Range in central Massachusetts, near the northern end of the Hartford basin outcrop belt. The Holyoke Range is topographically continuous with ridges in Connecticut that are underlain by a comparable sheet of mafic extrusive rock which Percival (1842) designated the Main Trap Sheet. W. M. Davis (1898) used the term Middle or Main flow for the Holyoke. The name Holyoke was extended into Connecticut by Rodgers, Gates, and Rosenfeld (1956, 1959).

Because I have found that the proportion of basalt in the Holyoke is much less than that of coarser-textured rocks, such as dolerite and even gabbro, I propose to drop the designation basalt. Instead, I here propose to change the designation to formation.

The Holyoke Formation underlies Totoket Mountain, Saltonstall Ridge, and Beacon Hill. The Holyoke is the most-resistant stratigraphic unit in the Branford and Wallingford quadrangles. Wherever it is exposed, it forms high, rocky ridges. At the NE end of Saltonstall Ridge, the outcrop belt narrows. This narrowing has been explained as a result of stratigraphic thinning brought about by the overlap and wedging of the flow against the W-dipping surface of an ancient fan near the basin-marginal fault (Longwell, 1937, p. 437). My mapping suggests that this change has resulted from postdepositional faulting.

Fresh exposures of the Holyoke Formation in the Branford quadrangle include: (1) the cut along the N side of the Connecticut Turnpike W of Saltonstall Lake; (2) along the S side of the Amtrack Railroad tracks just S of the Turnpike; (3) in the New Haven Water Company tunnel at the N end of Saltonstall Lake (Longwell, 1922, 1932); (4) in the North Branford quarry of Tilcon, Inc.; and (5) in an abandoned quarry at the S end of Beacon Hill. Numerous other fresh exposures of the Holyoke Formation are present on the upper parts of the steep slopes underlain by this unit.

The base of the Holyoke Formation is exposed in the several localities discussed for the Shuttle Meadow Formation. The top of the Holyoke Formation is visible on the S side of the railroad tracks west of Saltonstall Lake, in the S approach to the New Haven Water Company tunnel at the N end of Lake Saltonstall (Longwell, 1932, p. 132), and in hillside exposures on the SW slope of Saltonstall Ridge near its NE end, 0.4 mi W of Linsley Pond. These last-named hillside exposures were noted by Hovey (1889, p. 364, 371) and by Davis and Whittle (1889, p. 110-111), but they did not mention any faults.

The Holyoke Formation contains numerous varieties of mafic igneous rock that are well shown on Totoket Mountain.

On the basis of the textures, I infer that at least two distinct flow units are present on Totoket Mountain. Aerial photographs of the ridge suggest that more than two flow units may be present, although I have not mapped them separately. In the Turnpike cuts west of Lake Saltonstall, I have not found any evidence that more than a single flow unit is present. Similarly, despite his search for individual flow units, Longwell (1922, 1932, 1933) mentioned that he found only a single flow unit in the New Haven Water Company tunnel.

The Holoyke compares closely with the Preakness Formation (Second Watchung flow) of New Jersey. Cores through the Preakness Formation show a thickness of 310 m, with at least 5 flow units, two of which are separated by 3 m of sedimentary strata. "The 145-m thick basalt below the sedimentary layer has (sic) coarsely crystalline gabbroic layers as much as 11 m thick. The upper basaltic unit also contains gabbroic layers, but they are less than 8 cm thick. The coarsely crystalline layers may represent pockets of slowly cooled lava, segregation veins, or intrusive layers" (Fedosh and Smoot, 1988, p. 22). This, and other, similarities form the basis for

McHone's (1996a, b) conclusion that all the extrusives in the Newark-type basins were formerly continuous and formed a large plateau-basalt province.

East Berlin Formation

The East Berlin Formation was named by Lehmann (1959, p. 7) from the Town of East Berlin, Connecticut. The unit involved is the same one that Krynine (1950, tables 1 and 2, p. 31, 32) had designated as the "Upper sedimentary division of the Meriden formation." The East Berlin Formation includes part of Percival's Middle Shale and is identical with the Posterior Shales of Davis (1898).

The type locality of the formation is the roadcuts on Connecticut Route 72 just east of the Wilbur Cross Parkway, in the NW corner of the Middletown quadrangle. Lehmann's section here measured 325 feet thick, with base not exposed. Widening of the highway in 1961 increased the length of this exposure. Large new cuts on Connecticut Route 72 relocation and enlargement to a 4-lane divided highway in 1988 provide splendid new exposures showing the decidedly cyclic aspect of the formation.

The East Berlin Formation occupies the entire lowland enclosed by Totoket Mountain (including Lake Gaillard) and the curving lowland that lies parallel to and S and E of Saltonstall Ridge (including Lake Saltonstall). Where the formation consists of fine-textured strata (inferred ancient lake deposits), such as siltstones, very fine-textured sandstones, claystones, and shales, it is topographically weak and forms lowlands that typically are covered by fields of drumlins. Where the unit consists of conglomerates, however, as near the NE end of Saltonstall Ridge and the SW end of Totoket Mountain, however, it tends to form steep-sided ridges.

The most-continuous exposures of the East Berlin Formation are present in the New Haven Water Company's Sugarloaf tunnel, which extends eastward from the N end of Lake Gaillard. I have not seen these exposures; they were described by Thorpe (1929). The basal beds of the East Berlin Formation are visible in scattered natural exposures near the N end of Lake Gaillard, along the E shore of this lake, in the lower reaches of Roses Brook that drains into the lake on the E side, in the hills NW of Connecticut Route 80 NE of North Branford center, in the valley of Pisgah Brook S of the E end of Saltonstall Ridge, at the S end of the New Haven Water Company's tunnel at the N end of Saltonstall Lake, and in the cut on the S side of the Amtrak Railroad tracks, 0.2 mi. E of Lake Saltonstall. Strata higher in the formation are exposed along the E shore of Lake Saltonstall about half way along the lake from its S end and along the S side of the Amtrak Railroad tracks just W of the Hosley Avenue overpass. The upper beds of the formation are exposed near the basin-marginal fault NW of Pisgah Brook and S of the NE end of Saltonstall Ridge.

The East Berlin Formation closely resembles the Shuttle Meadow Formation and, like it, consists of a finer-textured facies of maroon siltstone and fine-textured sandstone, and, in localities adjacent to the basin-marginal fault, of a coarser-textured facies that consists of gray conglomerates. I mention some of the more-distinctive rock types. In the Amtrak Railroad cut

W of Saltonstall Lake, a light gray, fine-textured limestone, 1 ft. thick, is present approximately 1 ft. stratigraphically above the base of the formation.

The conglomerates in the formation are exposed underneath the power line northwest of Pisgah Brook. Clasts here are very angular for their sizes. They consist of pegmatitic rocks up to 2 ft. in diameter containing pink feldpsar; weathered vesicular basalt (one block measured 18 by 18 in.); quartz and quartzite; gneiss; and green schist. Other conglomerate is exposed 0.5 mi. to the NW, just E and W of Laurel Hill Road, at the power line crossing. Pebbles here consist of quartz and quartzite, pink feldspar, slightly weathered basalt, and green schist. The conglomerate exposed on the NW side of Route 80 just northeast of the intersection with Sea Hill Road is noteworthy for its abundant basalt clasts and nearly complete lack of feldspar.

In the Branford quadrangle, I have determined the thickness of the East Berlin Formation from the profile-sections controlled by the top of the Holyoke Formation and base of the Hampden Formation. The average value is 1,400 ft. By contrast, in the Middletown quadrangle, Lehmann (1959) reported a thickness of only 550 to 600 feet. A comparable change in thickness between southern Connecticut and central Connecticut also takes place in the Shuttle Meadow Formation. These thickness changes do not involve the extrusive sheets of mafic igneous rock. Although the details are not known, I relate them to differential subsidence on the actively subsiding Gaillard Graben. Whether such graben subsidence also affected the New Haven Arkose and Portland Formation is not possible to determine. The thicknesses of the New Haven Arkose in southern Connecticut and in central Connecticut are not known. Only a few hundred feet of Portland Formation are exposed in narrow outcrop belts in southern Connecticut, whereas several kilometers of Portlant occupy a wide outcrop belt in central Connecticut.

Hampden Formation

The name Hampden basalt was proposed by B. K. Emerson (1898a, p. 6) for the uppermost of the three sheets of extrusive mafic rock in the Newark succession. Presumably, the name was taken from Hampden County, Massachusetts, although Emerson did not specifially make this derivation. The Hampden applies to the unit that Percival (1842) had called the "Posterior Trap Sheet" and to which Davis (1898) had referred as the "Posterior" or "Upper Lava Flow." Rodgers and others (1956, 1959) extended the name Hampden Basalt into Connecticut. I propose to change the designation from "basalt" to "formation" because in the Branford quadrangle, I have found that what has been considered previously to be the "upper lava flow" consists of two sheets of mafic extrusive rock separated by an interbedded unit of sedimentary rocks.

The Hampden Formation is confined to the southwest-central part of the Branford quadrangle, where it underlies the curvilinear row of low knolls situated parallel to- and S and E of Saltonstall Ridge and of the lowland underlain by the East Berlin Formation. The Hampden Formation does not appear in that part of the Totoket transverse syncline which lies within the Branford quadrangle. A small outcrop area of the Hampden Formation that is separated from its main outcrop belt is present in the axis of the Pisgah Brook syncline in the hills NW of Pisgah Brook, 0.7 mi. N of the point where Chestnut Street crosses the Branford Water Supply Ponds.

My finding of this remnant of the Hampden Formation adjacent to the basin-marginal fault proves that this formation extends all the way to this fault, and does not lap out eastward against a former west-sloping fan surface, as has been suggested by W. L. Russell (1922 ms, 1922), by Longwell (1922, p. 234; l933, p. 98; 1937, p. 437, fig. 1) and by Rodgers (in Rodgers, Gates and Rosenfeld, 1959, p. 16). I differ from all previous workers (except Rodgers 1985, who accepted my work) in removing from the Hampden two outcrop belts of basalt adjacent to the basin-marginal fault NW of Branford center. According to the evidence exposed in the cuts on the Connecticut Turnpike, these are the distinctive extrusives from the Talcott Formation.

The low, rounded knolls underlain by the Hampden Formation tend to be elongated in the strike direction. In localities E of Lake Saltstonstall, a double-crested ridge is present, as mapped by Percival (1842).

The best exposures of the Hampden Formation are in Branford, in the New Haven Water Company's drainage ditch E of Lake Saltonstall, 0.8 mi. north of Interchange 53 on the Connecticut Turnpike, in the roadcut 0.25 mi. N of this ditch, in a large borrow quarry that was made for fill on the Connectciut Turnpike just north of this roadcut, and in a small quarry south of Laurel Hill Road 0.25 mi E of the junction with Brushy Plain Road. Fresh rock has been found only in these artificial exposures. Natural exposures of the basalt of the Hampden Formation have been much weathered; the rock has been deeply decomposed. During construction of the Connecticut Turnpike, the basalt of the Hampden was exposed behind the footings of the bridge piers for the Hosley Avenue overpass. These were visible only for a few months in 1957; during final construction, they were filled in and covered.

The middle siltstone member of the Hampden Formation is well exposed in the New Haven Water Company's drainage ditch and in the borrow quarry N of the ditch. The siltstone member was also exposed briefly in 1957, during construction of the Hosley Avenue bridge piers on the Connecticut Turnpike. The siltstone member is exposed naturally E of Lake Saltonstall about half way between the Hosely Avenue bridge over the Amtrak Railroad tracks and the New Haven Water Company drainage ditch.

In the areas E of Lake Saltonstall, the Hampden Formation consists of two sheets of extrusive mafic rock and an intervening siltstone. Percival (1842) is the only previous worker who remarked on the double-ridged characteristic of this formation in this area. In most other localities within the Branford quadrangle, and elsewhere in Connecticut, the composite nature of the Hampden Formation is not easily demonstrated. Another locality where the Hampden is composite is just north of the Sebethe River, near Westfield (Rice, 1906, p. 191).

The three parts of the composite Hampden Formation will be informally designated as lower basalt-, siltstone-, and upper basalt members. Their thicknesses are 60 ft., 40 ft., and 100 ft., respectively.

Portland Formation

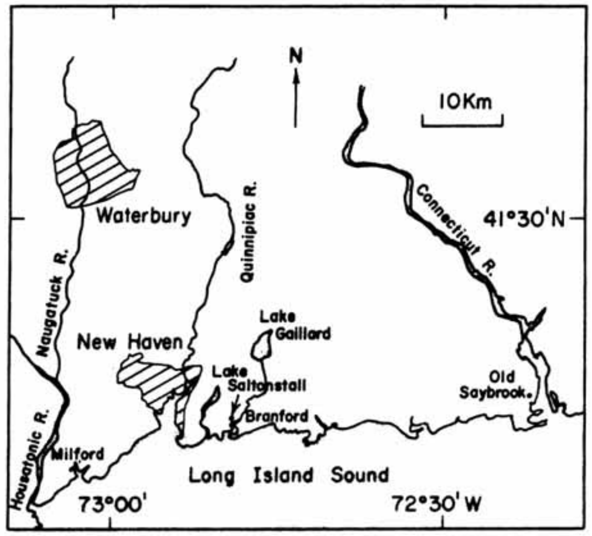
The Portland was first used as a name in the Newark succession as "Portland arkose" (Krynine, 1941, p. 1919; 1950, tables 1 and 3, p. 31, 32). Krynine chose the name from the town of Portland, Connecticut, for the "Eastern Sandstone" of Percival (1942) and of Davis (1898).

The Portland Formation underlies the broad lowland E of Lake Saltonstall. A much-smaller remnant of the formation is preserved in the Pisgah Brook syncline northwest of Pisgah Brook, 0.8 mi. due N of the eastern end of the Branford Water Supply Ponds.

Where the Portland Formation is fine textured, it tends to form lowlands that have been covered with till, commonly in drumlins. The coarse-textured facies of this formation, however, form steep-sided ridges.

The best exposures of the Portland Formation are located just S of Route 1, at the corner of Orchard Hill Road, behind a retaining wall beside a building occupied (in 1964) by the Tilo Roofing and Siding Company. During construction of the drainage ditches for the Connecticut Turnpike in the summer of 1957, the formation was briefly but extensively exposed, notably along the Branford Connector road SW of Cherry Hill, and NE of Cherry Hill. Although subsequently they have been covered, these ditch exposures were available long enough for me to make detailed studies and to collect specimens. Figure 10 shows a graphic log of part of the ditch section with emphasis on the deltaic aspects. Natural exposures of the fine-textured facies of the Portland Formation are present in the steep ravines E of Brushy Plain Road, 0.5 mi. west of the Cedar Street crossing of the Branford Water Supply Ponds. The only conglomerates found in the Portland Formation are in the small outcrop area in the axis of the Pisgah Brook syncline and along the north end of Cherry Hill Road, Branford, NE of the New Haven Water Company drainage ditch.

The Portland Formation seems to be conglomeratic in its lower part and much finer textured in its upper part. The two localities where conglomerate has been found lie close to the contact with the underlying Hampden Formation. One of the localities is adjacent to the basin-marginal fault, and the other lies 1 mi. W of this fault. The upper finer-textured beds do not change particle size even in localities adjacent to the basin-marginal fault. The coarse-textured conglomerates north of the Branford Water Supply ponds, which formerly were assigned to the Portland, have been found to underlie the Hampden Formation, previously thought not to be present here. Accordingly, I have assigned these exposures to the East Berlin Formation. The fine-textured facies of the main part of the Portland Formation in the Branford quadrangle provide a striking exception to the nearly universal depositional pattern that prevailed in most localities in the Hartford basin during the Late Triassic and Early Jurassic Periods. In these other localities, near the basin-marginal fault at all stratigraphic levels, basin-marginal rudites are present. Strata that are fine textured only a few miles away from this fault pass very abruptly into coarse deposits near the fault. I have found fine-textured strata with no indications of basin-marginal rudites in the Portland Formation only 400 ft. away from the basin-marginal fault. Other fine-textured Portland strata occur 0.4 mi distant from the fault.



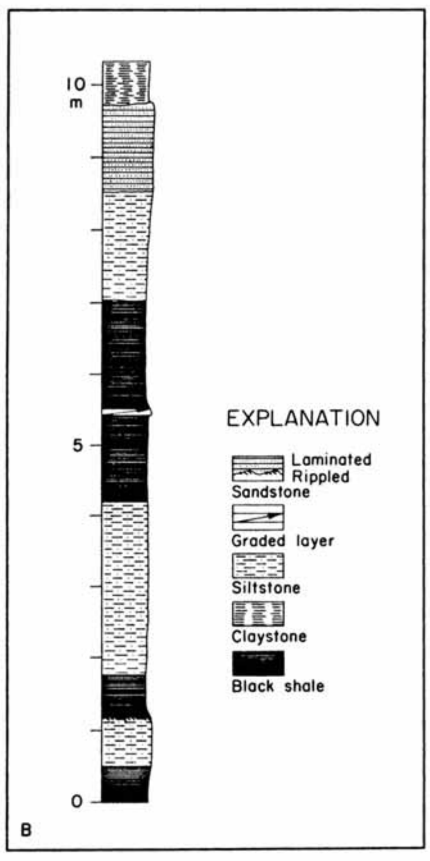


Figure 10. Graphic log, Portland Formation exposed temporarily during construction of drainage ditches along the Branford Connector Road to Connecticut Turnpike. (G. M. Friedman and J. E. Sanders, 1978, fig. 9-27, p. 260.)
A. Location map; tip of arrow locations graphic log of Figure 10B.
B. Graphic log of alternating kinds of sequences deposited on lacustrine deltas composed of fine-textured sediments. (Based in part on J. E. Sanders, 1968a.)

The coarse conglomerates of the Portland Formation are noteworthy for their large contents of vesicular-basalt boulders. Basalt boulders are also present in the coarser parts of the Shuttle Meadow and East Berlin formations.

The fine-textured parts of the Portland Formation consist of such varied rocks as maroon claystone, -siltstone, and -very fine-textured sandstone; black siltstone, and -shale with intercalated gray graded sandstones. I have measured two stratigraphic sections in these beds: from the ditches along the Branford Connector road of the Connecticut Turnpike and behind a low retaining wall at the Tilo Roofing and Siding Company.

In the Branford quadrangle, I estimate that the preserved thickness of the Portland Formation is 1,500 feet (based on profile-sections drawn from the geologic map). This represents only a small fraction of the thickness preserved in central Connecticut.

PALEOGEOGRAPHIC RELATIONSHIPS

Of special interest in the understanding of any sedimentary rock is the general paleogeographic (or paleoecologic) setting in which its antecedent sediments were deposited. For example, was the setting in the sea (marine) or in some inland continental basin (nonmarine)? Was the site of deposition in the tropics? In an ancient temperate zone? In a polar region? Where was it situated with respect to a former continental margin?

All available evidence demonstrates that the Newark basins were filled with nonmarine sediments. An attribute of great significance in any nonmarine setting is the hydrologic situation. Was water abundant or scarce? Was rainfall distributed seasonally? In the following paragraphs, I discuss some hydrologic possibilities in nonmarine basins in general terms and then review some of the relationships between water and deposition of sediments.

Hydrologic Situation in Nonmarine Basins

The hydrologic situation controls many geologic process and all biologic/botanical possibilities. The first-order control on the distribution of water in an area is position with respect to the Earth's latitudinal climate zones. For example, is the long axis of an elongate depositional basin parallel with or perpendicular to the Earth's Equator? During the early part of the Paleozoic, our region lay in the Southern Hemisphere and the edge of the continent was parallel to the Equator (Figure 11). By the beginning of the Mesozoic Era, however, the position of North America with respect to the Equator had shifted closer to its present setting. This is indicated by the paleoclimatic relationships implied by the Newark basins whose long axes trended perpendicular to the latitudinal climatic belts. Ancient coal swamps, which prevailed in Virigina, imply an equatorial rain-forest setting. By contrast, the ancient desert sands of Nova Scotia suggest a position in the world's arid latitudes (Paul Olsen, May 1994 lecture in Nyack, NY, NAGT section meeting).

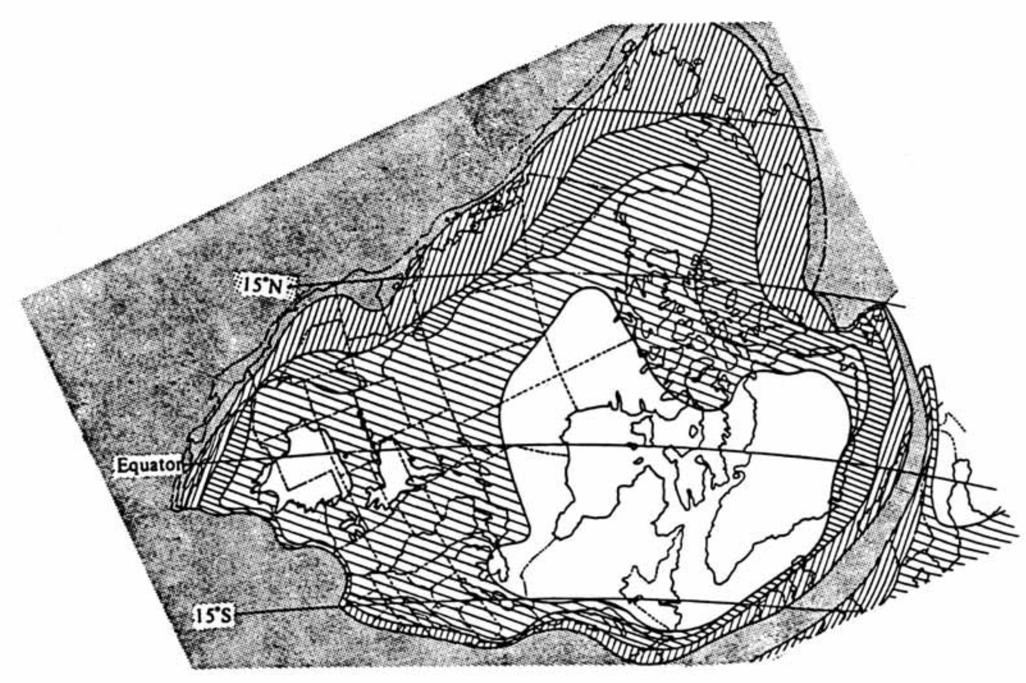


Figure 11. Paleogeographic map showing North America in its Early Paleozoic position astride the Earth's Equator, with what is now the eastern continental margin in the Southern Hemisphere as the southern continental margin. (C. K. Seyfert and L. A. Sirkin, 1979, fig. 10.4b, p. 252.)

One scarcely needs to emphasize the point that water controls organisms. If water is present, plants grow. If not, no plants can survive. And, without plants, no animals can exist. Dinosaur footprints (Figure 12), such as are found in some Newark strata, imply that during the Triassic-Jurassic time of sediment accumulation, dinosaurs were numerous. This, in turn, means that vegetation, hence water, was plentiful. How can evidence for abundant water implied by the large number of dinosaurs to make footprints and for lack of water implied by the footprints themselves be reconciled? Several such ways are possible. These include: permanent through-flowing rivers that head in areas where rainfall is abundant; ground water flowing basinward in shallow aquifers consisting of tongues of coarse sediments that extend from the marginal highland out into the basin-floor lowland; contrasting wet- and dry seasons; and climatic changes involving a shift from dry to wet and back to dry again.

Permanent Through-flowing Rivers

Two examples of permanent, through-flowing rivers that arise in a wet-climate zone and flows across a desert with enough discharge so that they do not dry out, are the Colorado River in SW USA and the Nile River, Egypt. As pictures taken from satellites amply demonstrate, the banks of the Nile are lined with trees. Only a short distance away from the river is a treeless desert. As pointed out by the pioneer American meteorologist, William Ferrel (1863), the annual flood of the Nile is controlled by the northward migration of the zone of vertically rising air that is associated with the sub-solar point (place on Earth where the Sun's rays arrive at normal incidence). This zone of updrafts is also a zone of torrential rainfall; it is known as the

Intertropical Convergence Zone (abbreviated ITCZ). According to Ferrel, during Northern-Hemisphere summer, when the ITCZ migrates northward away from the Equator, following the Sun, its torrential downpours soak the Ethiopian Highlands, the headwaters of the Blue Nile. The flood subsides when the ITCZ migrates southward taking its rainfall with it.

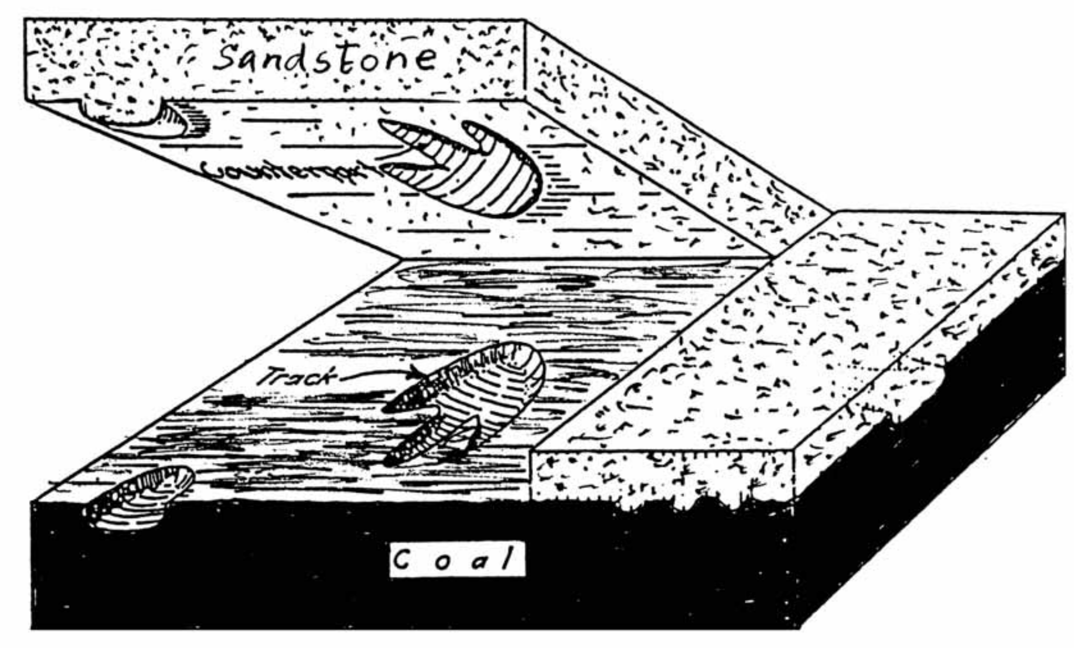


Figure 12. Sketch of several dinosaur footprints made in swampy Cretaceous material in what is now Wyoming that became a coal (black, below) that were preserved as counterparts on the base of the overlying layer of terrigenous sediment (stippled) that covered the footprints. The complete footprint shown was made by an enormous dinosaur; the length is 1 meter and the depth, 0.3 meter. (Slightly modified from R. R. Shrock, 1948, fig. 133, p. 178.)

Basinward Ground-water Flow in Shallow Aquifers

Another way a desert area can receive an abundant supply of water is via underground flow within tongues of coarse, permeable sediment that extend into the basin-floor desert from the basin-marginal highlands where rainfall is plentiful. The abundant rainfall in the highlands recharges such shallow aquifers, which can transported the ground water in the subsurface into a desert area. An example is the tropical "rain" forest at Lake Manyara National Park, Tanzania (35°50'E, 03°20'S). This forest is a distinct anomaly; it grows within an area where rainfall is a rarity; the surrounding territory is a bone-dry desert. But in the midst of this desert is a tract that is so lushly vegetated that it supports an abundant fauna including herds of large vertebrates. The plants are able to grow here because their roots derive water from shallow aquifers in the basin-marginal fan sediments. The aquifers are recharged in the highland at the margin of the basin. Thus this local Lake Manyara tropical "rain forest" is really a tropical "ground-water" forest.

Alternating Wet- and Dry Seasons

Another way in which water can appear in an otherwise-dry setting is for wet- and dry seasons to alternate. Rainfall could come more or less regularly during one- or two short seasons. Tropical regions affected by the seasonal migration of the ITCZ into each hemisphere and back again provide examples. At the extreme positions of this annual migration, only a single rainy season takes place. The monsoon belt of India is an example of a region receiving one-season rainfall. As with the Nile floods, the monsoon season in India accompanies the annual northward migration toward the Tropic of Cancer of the ITCZ (Friedman, Sanders, and Kopaska-Merkel, 1992, p. 282-286).

Localities closer to the Equator experience two rainy seasons that are of shorter duration than the Indian monsoon. One rainy season takes place when the ITCZ passes over during its migration from S to N, and the other, when the ITCZ comes back headed from N to S.

An interesting meteorological mystery is why the seasonal migrations of the ITCZ are not more regular than they are. After all, the position of the migrating subsolar point (place where the Sun's rays strike the Earth's surface at normal incidence) repeats itself within a few meters, year after year. Using the known limits of the latitudes reached by the migrating subsolar point, geographers define the Tropic of Cancer in the Northern Hemisphere and the Tropic of Capricorn in the Southern Hemisphere. But, the ITCZ, though driven by the location of the subsolar point, evidently is marching to a different drummer. For example, the west coast of South America is not subjected to an annual El Ni¤o. Instead, El Ni¤o's take place only when the seasonal migration of the ITCZ reaches as far as Latitude 15°S. I suspect that the orbital situation of the Moon may be a factor in all this, but can't prove this yet.

Change of Climate

Still-another way for creating hydrologic variation is climate change. During the Pleistocene Epoch, the tropical regions experienced dramatic shifts from wet times, known as pluvials, and dry times (interpluvials). The arid times in the tropics coincide with glacial-age climates elsewhere. The accompanying high winds propelled much dust high into the stratosphere, where the high-altitude winds sent it around the world. Interglacial times in the tropics were marked by abundant rainfall and lush vegetation; under these conditions, the amount of atmospheric dust was greatly diminished.

These times of contrasting abundance of atmospheric dust have been logged in the latest ice cores drilled in Greenland. Zones of dusty ice can be recognized by their higher electrical conductivity (related to the feldspar content in the dust). Continuous resistivity logging enables a graph to be constructed that shows dust content vs. depth (and down to a certain level, at least, depth is a direct function of age). The Greenland ice dated as having been deposited during the last glacial episode shows many sharply defined zones of dusty ice (implying glacial climate) alternating with zones low in dust, which imply nonglacial climate (Taylor and 9 others, 1993). An astonishing attribute of this electrical-resistivity logging of the ice cores is the abruptness of the change from dusty zones to low-dust zones. These imply that the climate shift from one mode to the other was very rapid (within a few tens of years).

The strata that filled the Hartford basin were deposited under contrasting hydrologic settings. Some of them were deposited in a deep lake that may have filled much of the basin, just as Pleistocene Lake Bonneville filled the Great Salt Lake lowland in north-central Utah 20,000 yrs ago. Typical deep-lake deposits are microlaminated black shales containing abundant remains of fossil fish. Other strata accumulated subaerially in a dry climate. Typical features of such strata are desiccation cracks, dinosaur footprints, and paleosol caliche.

Paul Olsen (1986) has given the name Van Houten cycles to lake deposits made during a change from deep water to shallow water (or even no water) and back to deep water again. Such changes characterize lakes in closed drainage basins. The water-level fluctuations are controlled by climatic changes.

Studies of the cyclicity by Van Houten (1962, 1964) and Olsen (1984 ms., 1986, and continuing from the Newark-basin cored borings) have indicated cycles having periods coinciding with the climatic cycles computed by Milankovitch based on variations in the Earth's orbital elements. The finding of such Milankovitch-type cycles in rocks as old as Late Triassic-Early Jurassic demonstrates that the computer-modelling gurus who claimed that the Milankovitch periodicities break down within a few million years have been using the wrong numbers in their formulae (Sanders 1995).

Some Relationships Between Water and Sediment

Key points about the relationships between water and sediment come into play when the flowing water transports the sediment, deposits the sediment, and may or may not rework the deposited sediments. By studying distinctive primary sedimentary structures in strata of sedimentary rocks, geologists are able to reconstruct some of these relationships. I illustrate this by considering two extreme sets of conditions: (1) a debris flow generated during a flash flood; and (2) a meandering stream that continues to flow between rain storms.

Debris Flows and Debris-flow Deposits

A debris flow generated during a flash flood is a one-shot affair--a kind of pasty wet flow having certain features analogous to those associated with a lava flow. The material flows over the landscape as a sheet, stops flowing, and not much more happens. The water may disappear downward by seepage. Once the material has been spread out into a layer, no more water is available to rework it. The interior of the sediment deposited may be essentially devoid of bedding. The sorting of the sediment will be generally poor; indeed, the contrast may be a between a fine-textured matrix and boulders or cobbles scattered at random within.

Meandering Streams and Point-bar Successions

A meandering stream typifies a stream that flows continuously between rainfalls, thus proving that it is fed by springs and/or general seepage from the ground water. The large amounts of water required are illustrated by a computation of how much rainfall is needed to keep the stream flowing. A tiny ditch flowing 1 cubic foot of water per second requires 60 cubic feet of water every minute, 3600 cubic feet every hour, and 24 x 3600, or 86,400 cubic feet per day. Taking 365.25 days per year, the total becomes 31,557,600. An acre-foot of water (an acre covered with water one foot deep) is 43,600 cu. ft. A square-mile-foot is 43,600 x 640 equals 27,904,000 cubic feet. Adjusting for runoff, infiltration, and evaporation, I conclude that the amount of water required to keep up a continuous flow of 1 cubic foot per second is the average annual rainfall in the New York region over a catchment area of about a square mile.

A continuously flowing meandering stream consists of a channel, whose position tends to shift laterally, and a flood plain, which is covered with water only during floods.

The sediments deposited by a continuously flowing, meandering stream consist of two contrasting kinds: (a) the coarser material deposited in the migrating channel; and (b) the finer material that was deposited on the flood plain between the channels.

As a meandering channel shifts, it leaves behind a patterned succession starting at the base with a scoured surface that is overlain by a coarse lag deposit. Higher up are cross-stratified coarse sands. At the top of the channel succession may be rippled fine sands. The thickness of the succession from the coarse lag to the rippled fine sands is equal to the depth of the flow in the channel during floods. The broader overbank areas, which are inundated only in floods, are the sites where fine sediments accumulate. The result of continued channel shifting and subsidence of the valley floor is a series of interbedded sandstones and siltstones/mudstones in which the particle sizes diminish systematically upward from the channel-floor lag to the overbank fines (Figure 13).

In the newly fashionable buzz words of "sequence stratigraphy," a patterned succession deposited by the lateral shifting of a stream channel is known as an upward-fining autocyclic parasequence.

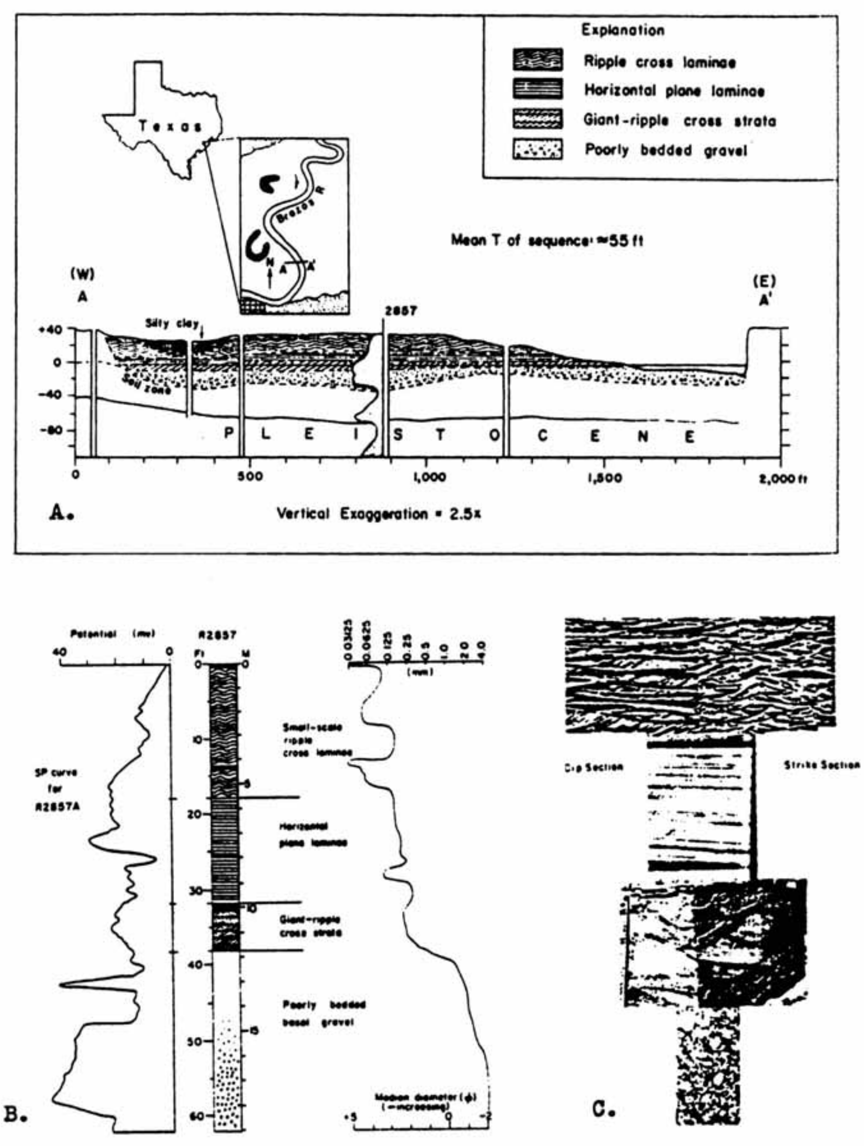


Figure 13. Point-bar succession deposited by meandering channel of Brazos River, SE Texas, based on borings made by Shell Development Company, Houston. (G. M. Friedman and J. E. Sanders, 1978; A, fig. 8-41, p. 222; B and C, fig. 8-43, p. 225; both based on H. A. Bernard and others, courtesy R. J. LeBlanc, Sr.)

A. Location of profile across flood plain; notice that the depth of water during fair weather is less than 20 feet (about 5 m), as shown at the right-hand end of the profile. By contrast, the mean thickness of the point-bar succession is 55 feet (about 17 m). This relationship proves conclusively the importance of floods in determining the thickness of the point-bar succession that will be recorded in the geologic record.

B. Detailed stratigraphic log and spontaneous-potential (SP; a kind of electrical log invented by the Schlumberger brothers) log for two closely spaced borings (R2857 for stratigraphic log; R2857A for SP curve). Curve at right shows mean diameter of sediment particles.

C. Photographs of the internal structures in sands at different levels in the succession.

Primary Sedimentary Structures

Of particular interest today are the features made in coarse sediments. One of the problems is to determine the bedding and to look for features showing current activity. This is usually expressed by finding parts of strata composed of finer sediment within the coarser parts (Figure 14).

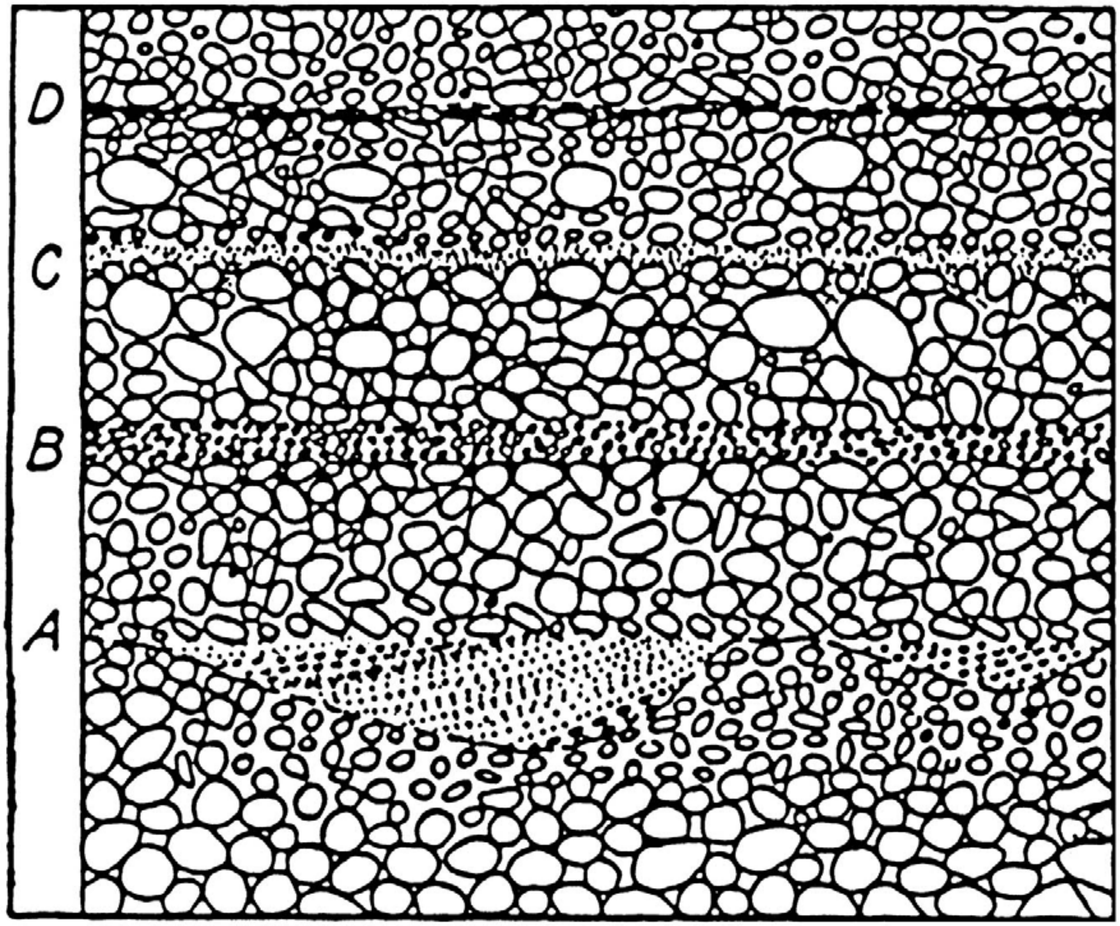


Figure 14. Sketch of gravel (or conglomerate) showing how bedding is revealed by finer sediment in planar layers (such as B, C, and D) or in lenses (as in A). (R. R. Shrock, 1948, fig. 3, p. 12.)

It is possible to use cross strata to determine the direction of flow of the ancient currents. The key to interpreting cross strata is that they dip in the downcurrent direction. The main point to be established before the interpretation can be considered complete is to determine the three-dimensional attitudes of the cross strata. If they are planar, then the interpretation is not complicated (Figure 15A). If they are cuspate (spoon shaped), the one needs to find the median line of the cusp. Cuspate cross strata dip through directions that may span an azimuth of 270°. Cuspate cross strata are concave downcurrent (Figure 15B).

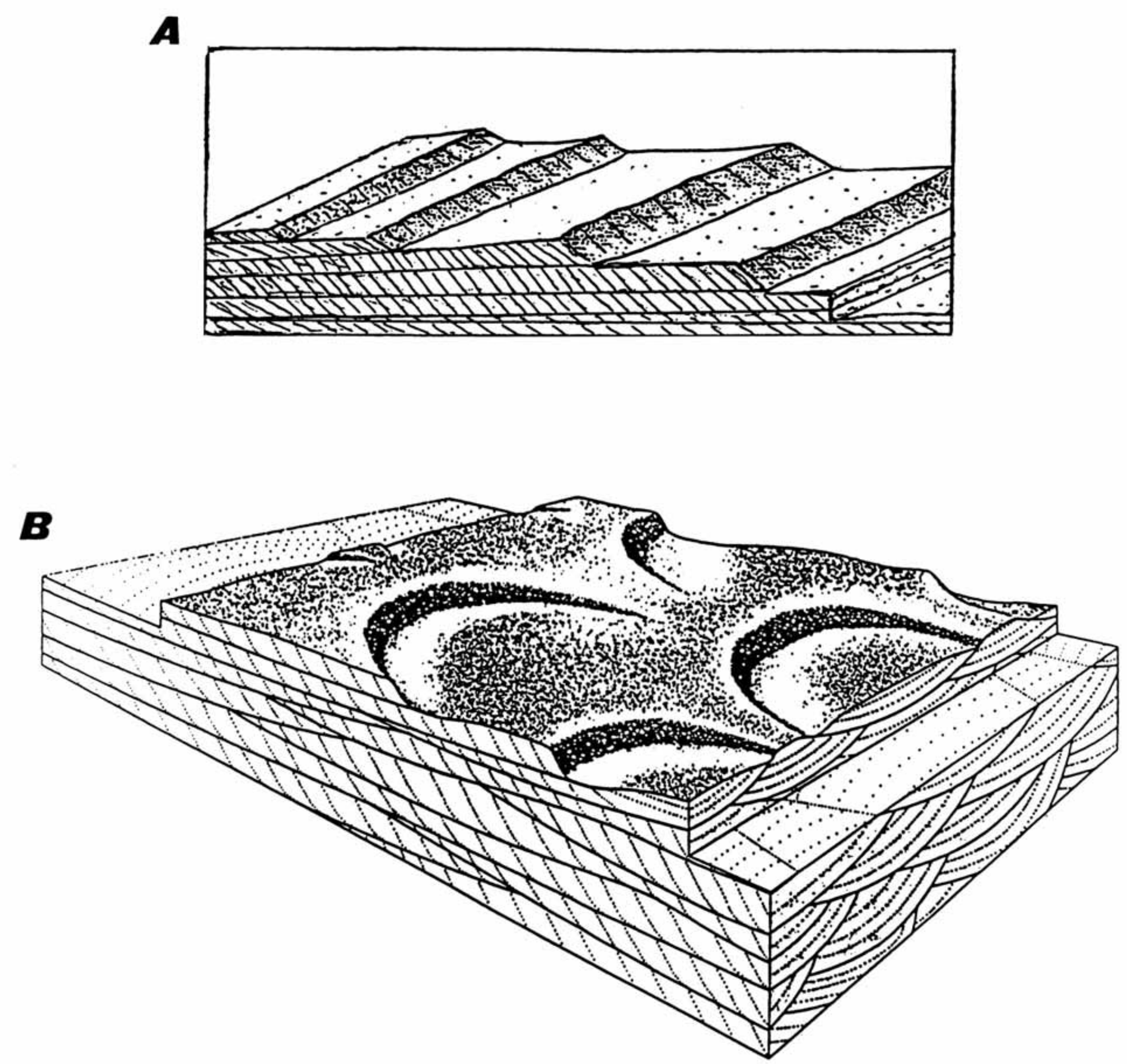


Figure 15. Sketches of contrasting shapes of bed forms created by a current flowing from left to right and cross strata resulting from their downcurrent migration.
A. Linear bed forms create planar cross strata. (G. M. Friedman, J. E. Sanders, and D. C. Kopaska-Merkel, 1992, fig. 5-19, A, p. 166.)
B. When cuspate (lunate) megaripples migrate downcurrent trough-type cross strata form. In sections that are parallel to the current, trough cross strata and planar cross strata look about alike. The difference between them is immediately apparent in sections normal to the current. (H. E. Reineck and I. B. Singh, 1980, fig. 52, p. 43.)

ASSOCIATED MAFIC PLUTONS

In addition to the sheets of extrusive igneous rock described as stratigraphic units, are various intrusive bodies (i. e. plutons, such as the sheets forming West Rock, Pine Rock, Mill Rock, East Rock, and Rabbit Rock in New Haven; the buttress dike; Mount Carmel, and dike swarms in Fair Haven). Our interest in these will be chiefly from the point of view of the contact effects they exerted on the New Haven Arkose.

In passing, however, especially in view of the work Merguerian and Sanders have carried out on the Palisades (Merguerian and Sanders, 1992a; 1995a, b, c, d), I note that in a quarry in the West Rock ridge, New Haven, CT, a layer of conglomeratic arkose produced a branching, irregular clastic dike exhibiting sharp contacts which was intruded upward more than 10 m into the dolerite sill (Walton and O'Sullivan, 1950). The particles within the clastic dike include several large pebbles, one of which was transported 0.6 m above the base of the sill. According to Walton and O'Sullivan, the clastic dikes were intruded at a temperature of roughly 400°C and a pressure of 0.4 Kb.

GEOLOGIC STRUCTURE

In this section, I include folds, faults, and the relationship of folds to faults. Use Figure 1 (on cover) as a reference to this discussion.

Folds

The fact that the outcrop belts of the resistant sheets of mafic rocks are not straight but curved demonstrates that the interpretation of the geologic structure as a simple homocline (Figure 16) is not accurate. Instead of being strictly linear, as would be the eroded edges of resistant strata in a true homocline, the ridges that are underlain by the sheets of extrusive igneous rock are curvilinear. Their pattern is more like that of a group of offset letter "C's" instead of "I's" as in a simple homocline. This curvilinear pattern has resulted from the erosion of a series of folds whose axial planes are perpendicular to the basin-marginal fault. Accordingly, JES has classified these folds as being transverse folds. (See detailed discussion in Merguerian and Sanders, 1991c; 1994.)

Most of the folds that I have mapped in the Branford quadrangle are of the transverse variety. In addition, many of them are small enough to be appreciated by everyone having a sense of three-dimensional relationships. For example, on the R-hand side of block diagram of Figure 6 is shown the North Branford anticline, which intervenes between the Saltonstall syncline on the SW and the Totoket syncline on the NE. My mapping indicates that the North Branford anticline is not a simple fold as shown in Figure 6, but that several faults trending parallel to its axis are present.

One fold that is too large for most geologists to comprehend is what I have designated as the Danbury anticline. According to my interpretation, along the NE limb of the Danbury anticline, the base of the Newark, dipping NE, is brought against the basin-marginal fault in New

Haven Harbor. Moreover, the steep dips (45° or so at Route 1, and steepening to the S to about 75°) in the Newark strata are a part of the Danbury anticline.

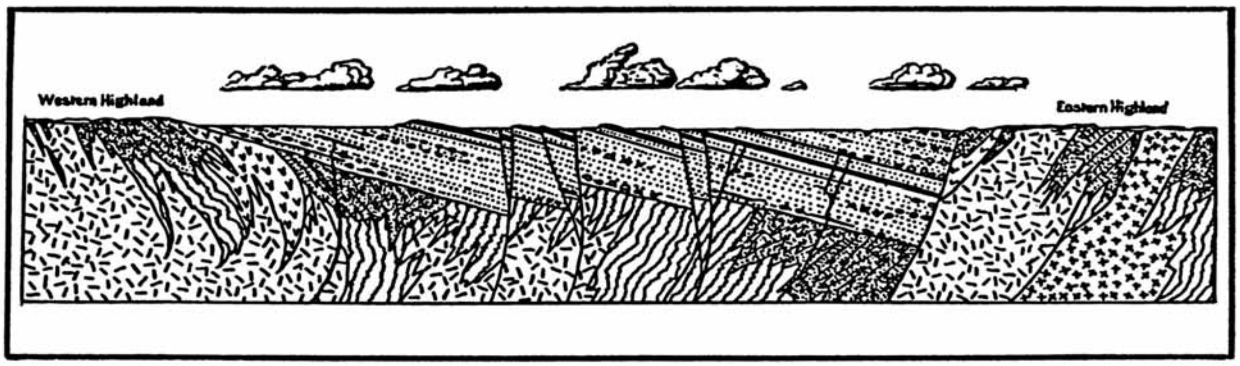


Figure 16. Profile-section through Hartford basin in latitude of central Connecticut showing regional eastward dip of the strata and the postdepositional faults. (Barrell, 1915, fig. 2.)

Faults

The major fault in the vicinity of our trip is the basin-marginal fault. The presence of this fault is indicated by the existence of Newark strata and/or extrusive igneous rocks on one side and pre-Newark metamorphic rocks of the Eastern Uplands province on the other. The basin-marginal fault has affected the immediately adjacent rocks, but has not created anything like mylonite. I emphasize this point, because in the metamorphic rocks of the Eastern Uplands in Branford are some NW-dipping mylonites that some have acribed to the effects of the basin-marginal fault. I reject this interpretation. The mylonites formed during extreme deformation of the metamorphic rocks. Moreover, the mylonites trend away from the basin-marginal fault.

Other faults are present within the strata filling the Hartford basin and are recognized on the basis of the offsets of geologic contacts. We shall examine faults of this kind at Stops 7 and 8.

Relationship to Folds and Faults

C. R. Longwell (1922) was the first to point out that after these folds had formed, they were offset by later faults which were not related to the folding. I have tried to extend this analysis one step further by using the displacement of the vertical axial surfaces of some of these transverse anticlines to infer the existence of strike-slip faults (Sanders, 1962a). Only a few geologists who have expressed their opinions about the structural history have paid much attention to the folds (W. M. Davis, 1888, 1898; W. L. Russell, 1922 ms. 1922; and C. R. Longwell, 1922, in Connecticut; N. H. Darton, 1890, in New Jersey; and Girard Wheeler, 1939 for both Connecticut and New Jersey). Obviously, geologists who have not recognized the existence of these folds find no basis for my view that the horizontal offsets of the vertical axial surfaces of some of the transverse anticlines serve as proof of the existence of strike-slip faults. All those who have glossed over- or ignored the transverse folds have tended to doubt the existence of such "non-tensional" features as strike-slip faults. Luckily, we have never doubted our eyes on this matter (Sanders, 1962a; 1963; Merguerian and Sanders, 1994a, b).

The abrupt ending of many folds having vertical axial surfaces disposed at right angles to the basin-marginal fault (Sanders, 1963) suggests that the fault served as a zone of adjustment for these folds during one or more episodes of deformation that took place after sediments had ceased to accumulate in the basin.

Clearly one's explanation of post-Newark folds and -faults basically depends on how one interprets the orientation of the Newark strata. At one end of the ideological spectrum are those who insist that the Newark strata assumed their present attitudes as a result of the operations of the same geologic machinery that caused the Newark basins to form, to subside, and to accumulate sediments. At the other end of this spectrum are those few (including Sanders and Merguerian) who insist that the strata were essentially horizontal when deposited and that the modern-day lack of horizontality requires a postdepositional compressive tectonic explanation.

The ultimate in horizontal reference planes is the top of an ancient lava flow; it serves as a kind of gigantic level bubble. Three complexes of ancient lava flows and interstratifed sedimentary strata are present in the filling of the Hartford basin (the tilted-, eroded edges of which now form curvilinear ridges, such as Saltonstall Ridge in the Branford quadrangle, CT). As we shall see, field relationships adequately demonstrate the parallelism of these three sheets of extrusive igneous rocks. The attitudes of these extrusive sheets and their associated sedimentary strata define at least two sets of folds.

QUATERNARY DEPOSITS

The Quaternary deposits of the New Haven region include various sediments of Pleistocene- and Holocene ages. Some Pleistocene deposits were made by the advances of several glaciers that flowed across the region from NW to SE and from NNE to SSW. Other Pleistocene sediments accumulated during the great meltdown stage of the latest glacier (Woodfordian). The thickest Holocene deposits have been deposited along the shores of Long Island Sound.

Pleistocene Deposits

As mentioned in a previous section, Pleistocene glaciers flowed across the region from two directions: (1) from NW to SE, and (2) from NNE to SSW. The evidence for such flow includes striae on the bedrock, orientations of the long axes of drumlins, and provenance data in the tills.

In the lowlands near New Haven, Flint's mapping has shown that bodies of outwash fed by several rivers extend into New Haven harbor. These were deposited simultaneously with fine-textured, laminated clays, inferred proglacial lake deposits in the southern Quinniapiac Valley. (See Figure 7, area marked by square pattern in NE corner). These laminated clays have been interpreted as varves, that is, deposits made during a yearly cycle. Antevs (1922) studied the varved clays in the then-active brick pits (lower unit in Figure 17) and found three overlapping sequences of varves that he inferred represented 732 years' worth of sediment. Schove (1984, p. 368) has assigned these Quinnipiac Valley varves counted by Antevs to the time period between 16,500 and 15,500 BP. (I think this assignment is probably too old by as much as 3,000 years, but that is another story.)

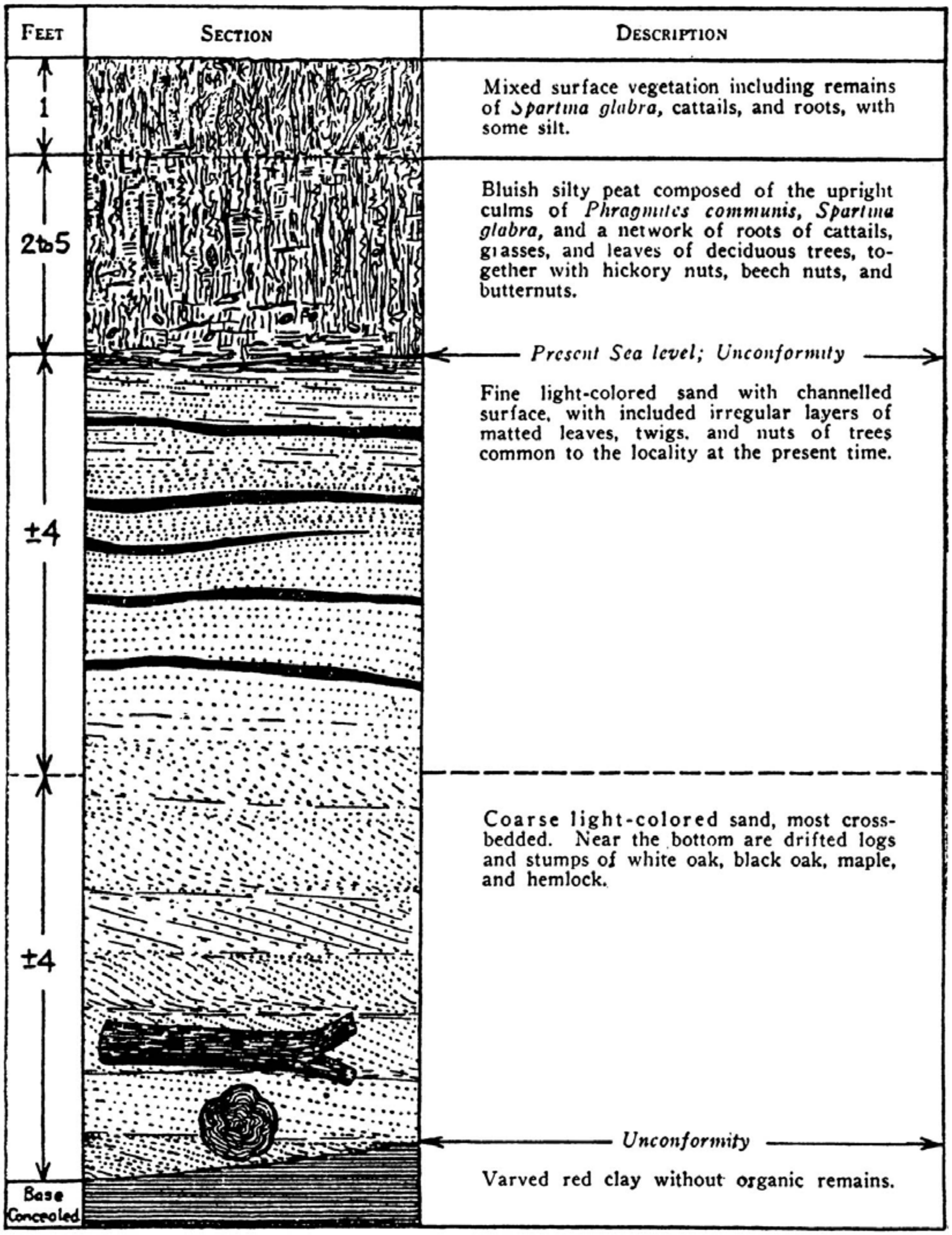


Figure 17. Stratigraphic section of Holocene sediments in Stiles clay pit, opposite Montowese, Quinnipiac Valley, Connecticut. (R. W. Brown, 1930, in R. F. Flint, 1930, fig. 42, p. 263.)

Flint (1930, p. 101) cited Dana (1884) as the source of a report that a dropstone erratic of dolerite, four feet in diameter, had been taken from a Quinnipiac clay pit.

Holocene Sediments

After the outwash had been deposited, a period of erosion ensued during which the topmost layers of outwash were removed and some relief carved. Thereafter, the modern sea arrived and along its margins, estuarine sands and saltmarsh peats were deposited. Information on the thickness and characteristics of these Holocene deposits comes from borings in New Haven harbor (where the maximum thickness of estuarine silt is about 50 feet; Figure 18) and from exposures in the Quinnipiac Valley brick pits (where a thickness of about 20 feet is seen; Figure 19). (See also Figure 17.)

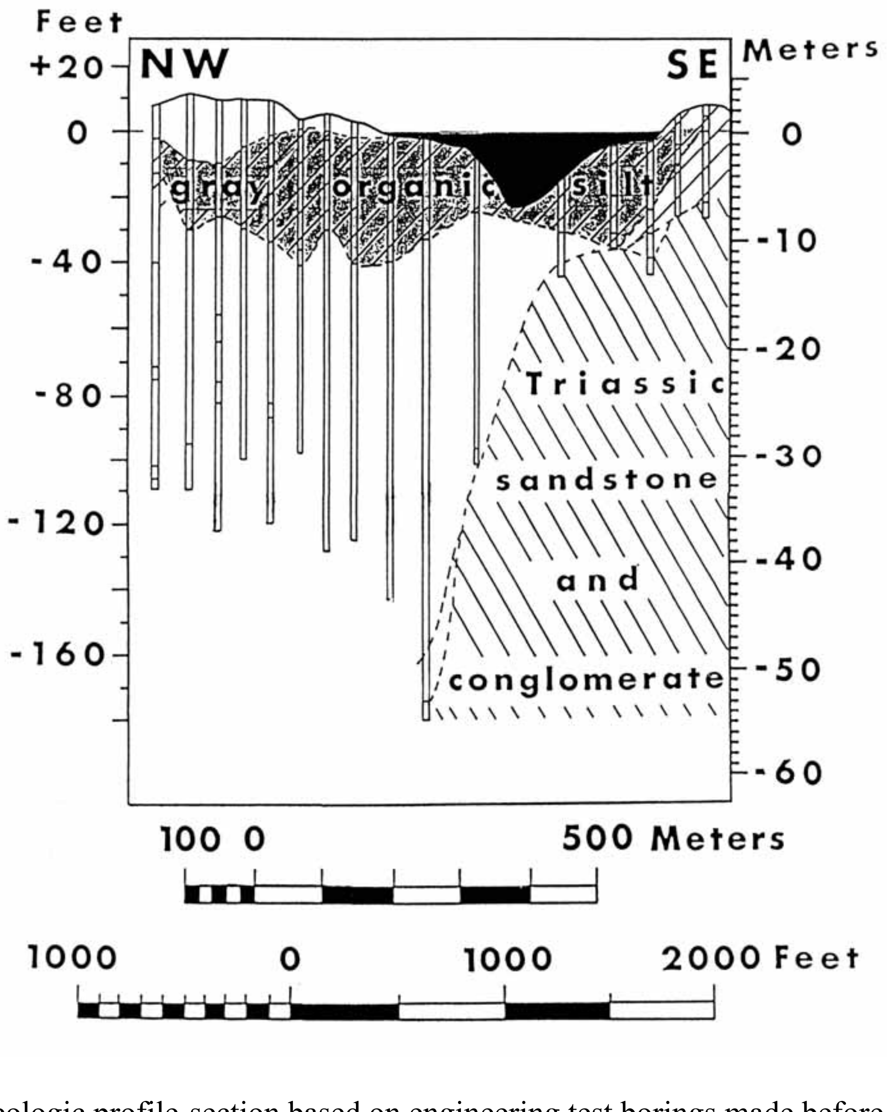


Figure 18. Geologic profile-section based on engineering test borings made before the construction of the I-95 bridge across the Quinnipiac River, New Haven, CT. (J. E. Upson, E. B. Leopold, and Meyer Rubin, 1964.)

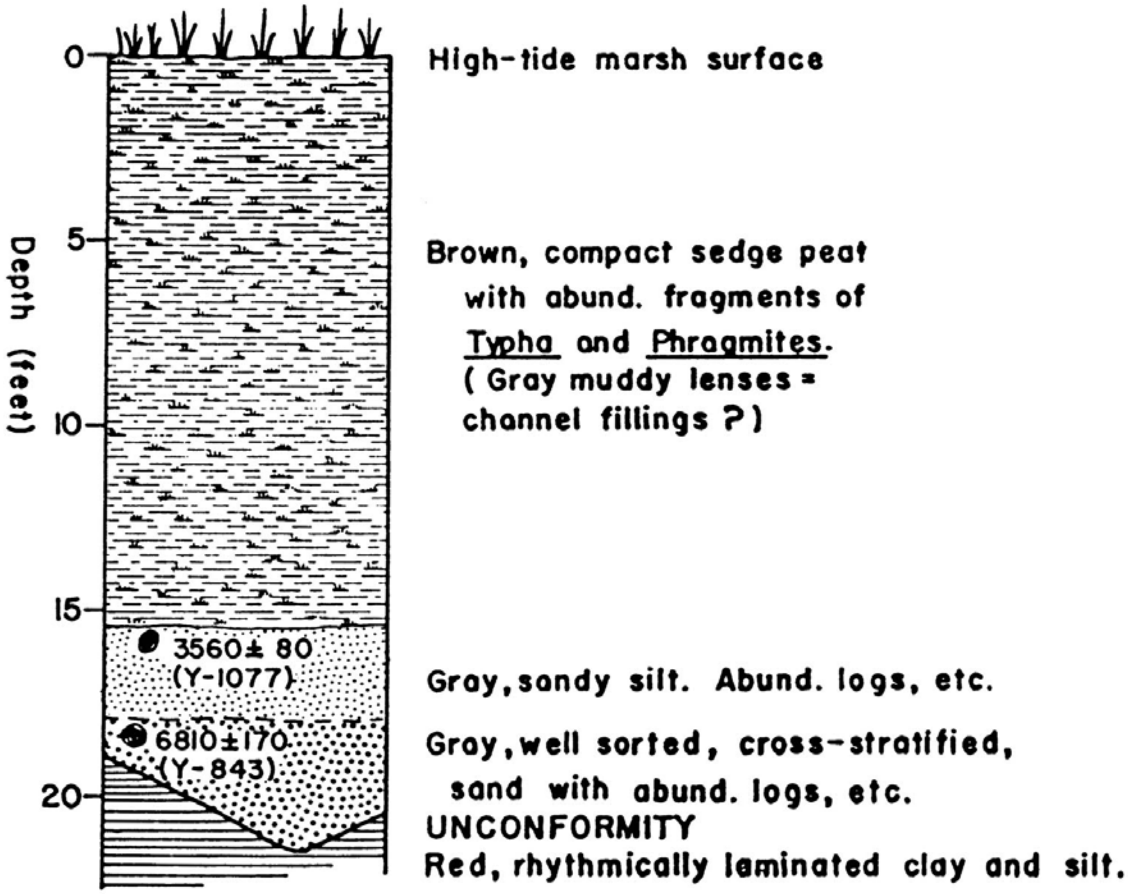


Figure 19. Section through Holocene sediments exposed in Quinnipiac Valley, showing results of radiocarbon dating of fossil wood. (A. L. Bloom and C. W. Ellis, Jr., 1965, fig. 2, p. 2.)

DRAINAGE HISTORY

The drainage history of Connecticut extends back to the early part of the Mesozoic Era, when the Hartford Basin was being filled with sediment. Evidence exists for several post-basin, pre-glacial episodes of drainage development. Less certain is the number of episodes of drainage rearrangement that took place during the Pleistocene.

Drainage During Filling of Hartford Basin

As mentioned, provenance data demonstrate that many early Mesozoic rivers flowed from what is now the Eastern Uplands into the Hartford basin. A current favorite pastime is to show that not all rivers associated with the Hartford basin flowed from E to W, and thus that the Hartford basin-filling strata did not extend much farther W than their present outcrop limit. I have not yet seen provenance data that is totally compelling with respect to this point.

The provenance data (Krynine, 1950) and the cross strata in the Newark strata of the Southbury outlier show that the Late Triassic-Early Jurassic drainage flowed from E to W, from E of the basin-marginal fault along the E side of the Hartford basin all the way to South Britain.

Post-Basin, pre-Glacial Drainage

The next possible time for drainage change was in the middle of the Jurassic Period in connection with the uplift- and breakup of the Newark-Hartford basin complex, an event that I think was a major one, but which many think never happened. During this time, the regional arch formed with its axis lying W of the east-dipping strata at South Britain and E of the W-dipping strata of the Newark basin.

This period of erosion culminated in the Cretaceous-age Fall Zone peneplain, whose traces in Connecticut have been studied by Flint (1963a). A valley that may have formed at this time lies buried beneath New Haven harbor (Sanders, 1965, 1988 ms., 1994; Haeni and Sanders, 1974; Lewis and Needell, 1987). (See Figures 08 and 09.) The age of this valley is not known, but one possible interpretation is that it extends to the WSW from New Haven harbor and disappears by going underneath the Upper Cretaceous strata underlying western Long Island. If so, it would be the same age as the strike valley at the base of the Newark Supergroup that passes beneath the Upper Cretaceous on western Staten Island.

Because the Upper Cretaceous coastal-plain strata probably covered parts of all of Connecticut and Massachusetts (at least all of the Hartford-Deerfield basin-filling strata to keep them out of circulation), we can infer that no drainage systems formed during the time (Late Cretaceous to the end of the Miocene) while western Connecticut was subsiding and receiving sediment during its second passive-margin phase. After this phase, the first time when erosion could have started again is late in the Miocene Epoch (or early in the Pliocene Epoch), when New England was regionally elevated, all traces of any former updip extension of the coastal-plain strata were removed, and the depression now occupied by Long Island Sound was eroded.

The "Sound River"

The name "Sound River" has been given to the river that is inferred to have eroded the valley now occupied by Long Island Sound. Presumably, the drainage in the Sound area was analogous to the modern Delaware River, which flows along the Inner Lowland of the coastal plain. Figure 20 shows a series of four stages in the drainage history of northeastern United States according to Veatch (1906).

Pleistocene Drainage Changes

The relationships between Pleistocene glaciers and drainage were complex; just how complex one is prepared to accept depends on how many glacial episodes may have affected the region and how much rearranging accompanied each glacial advance and -retreat. This statement may seem self evident, but it is included because most of the students of the drainage history of Connecticut have thought in terms of a single Pleistocene glaciation and some of them have been persuaded that the effects of this glacier on the landscape and drainage were minimal.

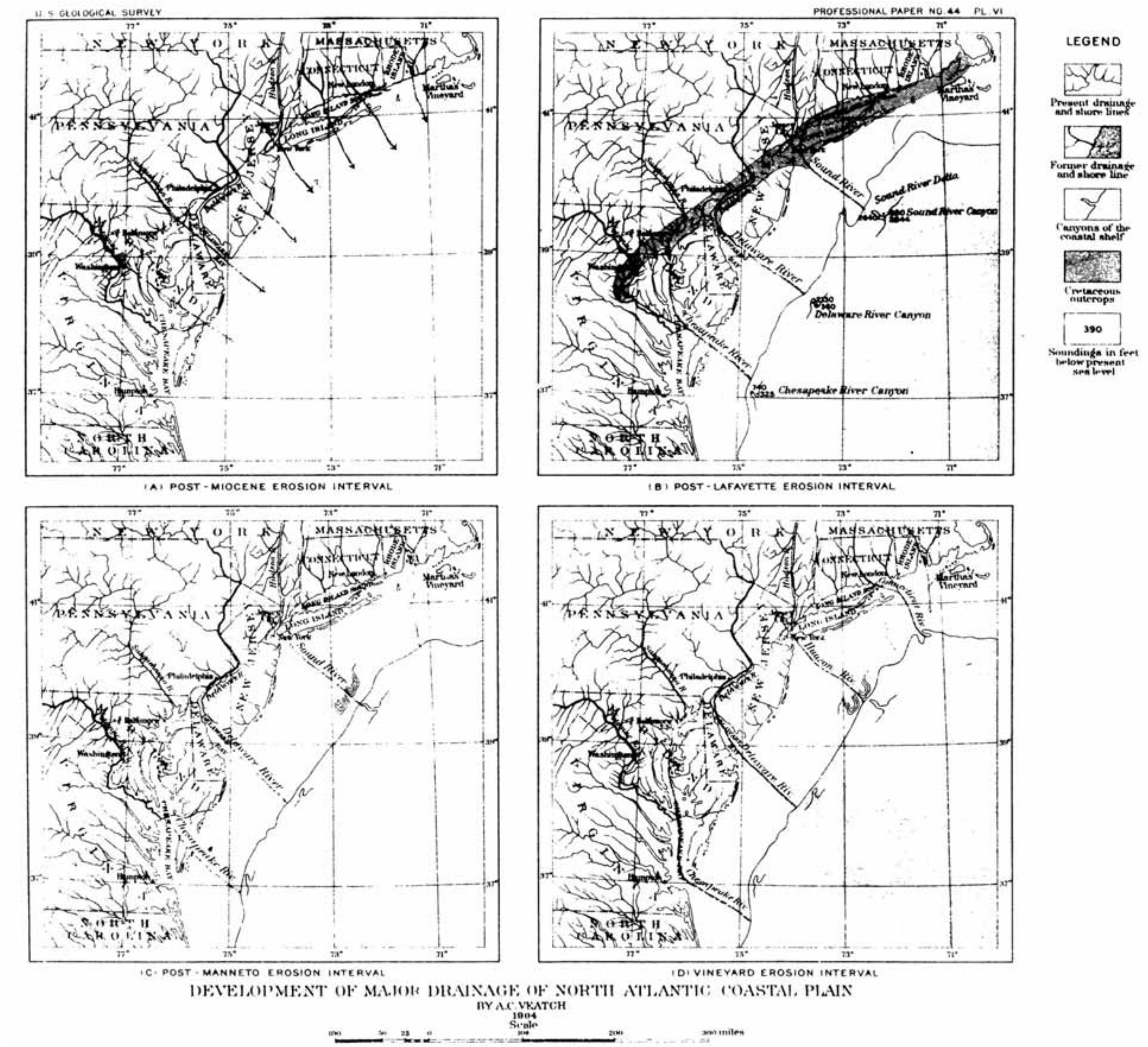


Figure 20. Maps showing inferred drainage at four episodes in post-Miocene time. (A. C. Veatch, 1906, plate VI.)

A continental glacier would tend to deepen any valleys trending parallel to the glacier's flow direction and to fill any valleys trending at a high angle to this direction. Each glacial advance would terminate all previous drainage and each glacial retreat would enable new drainage networks to form. Ithink that some of the new drainage may have been initiated on the top of the ice itself. If this happened, then some anomalous cross-axial drainage routes, such as that of the Housatonic River across the Housatonic Highlands in northwestern Connecticut, for example, conceivably could have been established by superposition from the glacier.

The uniformity of flow directions associated with the glaciers that came from the NW and traveled SE, a rectilinear pattern found on even the highest ridges in today's landscape, suggests to me a thick glacier whose flow direction was determined by the slope on the top of the ice sheet. Any rivers that began on the top surface of such an ice sheet would have been afforded numerous possibilities for superposition. How many times such thick glaciers overspread southern New England is not known, but I think the minimum number is 3 (Table 3).

Superposition or rivers from the top of a continental glacier is a concept that has not been considered by previous students of drainage history. Many such students have visualized the possibility that modern rivers may have attained their present locations as a result of superposition, but they supposed that the only way this could happen would be from the now-eroded former landward extensions of the coastal-plain strata.

Geophysical studies of the subbottom sediments in western Long Island Sound have shown that a U-shaped valley, trending more or less E-W, and with its thalweg extending down to about 600 feet below modern sea level has been cut into the coastal-plain strata (Grim, Drake, and Heirtzler, 1970). I think that this U-shaped valley was carved by one of the glaciers that flowed from the NW to the SE until it reached the escarpment facing the inner cuesta lowland at the eroded edge of the coastal-plain strata (Figure 21). This escarpment probably diverted the ice and caused it to flow nearly W-E.

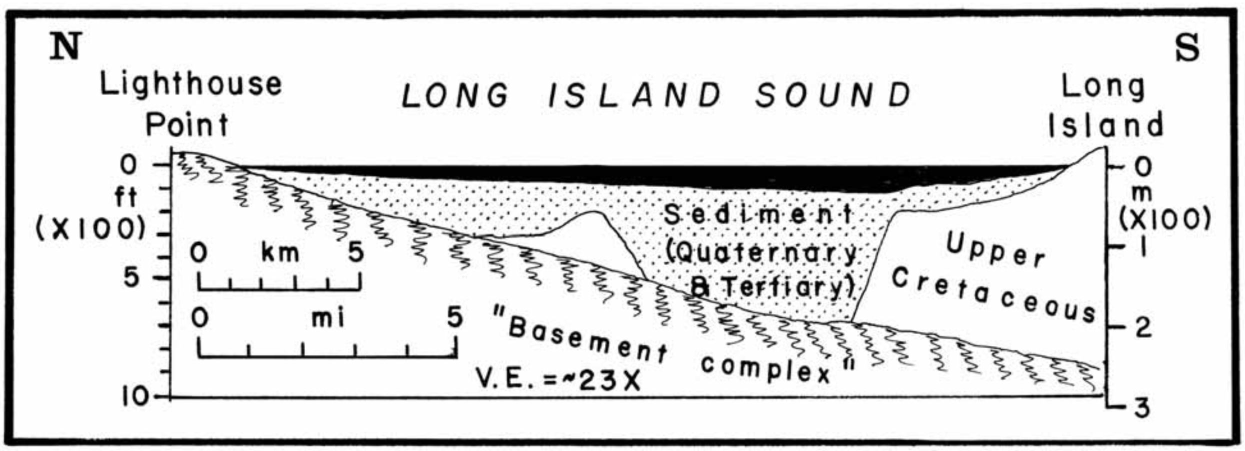


Figure 21. North-South profile-section across Long Island Sound from off Lighthouse Point, New Haven, CT, along West Longitude 72°53'. Water depths from NOS chart. Water of Long Island Sound shown in black. (Subbottom relationships from M. S. Grim, C. L. Drake, and J. R. Heirtzler, 1970, fig. 12, p. 661.)

Table 3 shows the Sanders-Merguerian correlation of the Pleistocene units on Long Island that show the relationships of the post-Manneto and Vineyard erosion intervals.

As mentioned in a previous section, during the melting- and retreat of the latest Pleistocene ice, large lakes formed in the important lowlands--Long Island Sound and the Central Valley in Connecticut and Massachusetts (Ashley, 1972, 1975). In these lakes were deposited varved sediments that Antevs (1922) and Schove (1984) used to assemble a chronology of glacial retreat.

Relationships of Modern Rivers to Hartford Basin-Filling Strata

A glance at a regional drainage map shows a striking difference between modern large rivers and the orientations of the elongate areas underlain by the filling strata of the Newark and Hartford basins. The paths of two major rivers, the Hudson and the Delaware, bring them close to or across the outcrop areas of the Newark basin-filling strata. The Delaware cuts directly across the outcrop of the Newark basin fill. The Hudson follows the basal Newark strike valley. By contrast, the Connecticut River flows along the length of the outcrop of the Hartford basin-filling strata. No major rivers flow across the area underlain by the Hartford basin-filling strata.

The Connecticut River

The Connecticut enters the outcrop area of the Hartford basin-filling strata at The Notch through the Holyoke Range. From there, it flows in a shallow channel more or less straight S to Middletown, CT. Just above Middletown, the Connecticut bends 45° to its left and crosses gneisses and other metamorphic rocks of the Eastern Uplands in its path to Long Island Sound.

Dana (1882, 1883b, 1884) inferred that the Connecticut formerly flowed in the strike along the W edge of the outcrop of the Hartford basin-filling strata and entered Long Island Sound at New Haven Harbor. Today, the major stream feeding into New Haven Harbor is the Quinnipiac, which heads in this west-edge strike valley, but leaves it by flowing through a gap at Plainville.

FLAPPING OF ARMS (AND GUMS)

Nearly all currently fashionable interpretations about the Newark strata begin with the phrase "rift basin." Such basins are diagnostic features of extensional tectonics. With respect to the Newark basin, the concept of rift tectonics has been refined slightly by including the notion of "reactivation tectonics." And, now we are beginning to hear words like "inversion tectonics." And, praise be! "compression" and "folding." The following remarks present my view that the Newark-type basins are definitely NOT rift basins. I start by presenting my understanding of what rift basins really are.

EXTENSIONAL TECTONICS; RIFT BASINS

Bird and Dewey (1970) first suggested that the Newark troughs formed after plate spreading and "extensional necking." Subsequently, this concept has been elaborated by many others; the diagnostic products of such lithosphere stretching are rift basins.

The fundamental features of extensional tectonics are listric normal faults that are steep at the Earth's surface, but that curve around to a horizontal orientation at a depth of 15 km or so, where the rheological properties of the lithosphere change from brittle to ductile (Figure 22). The normal faults in the extensional network do not extend laterally along the Earth's surface for great distances; they die out. Beyond where one fault ends, another may appear. In between is a relay ramp (Figure 23).

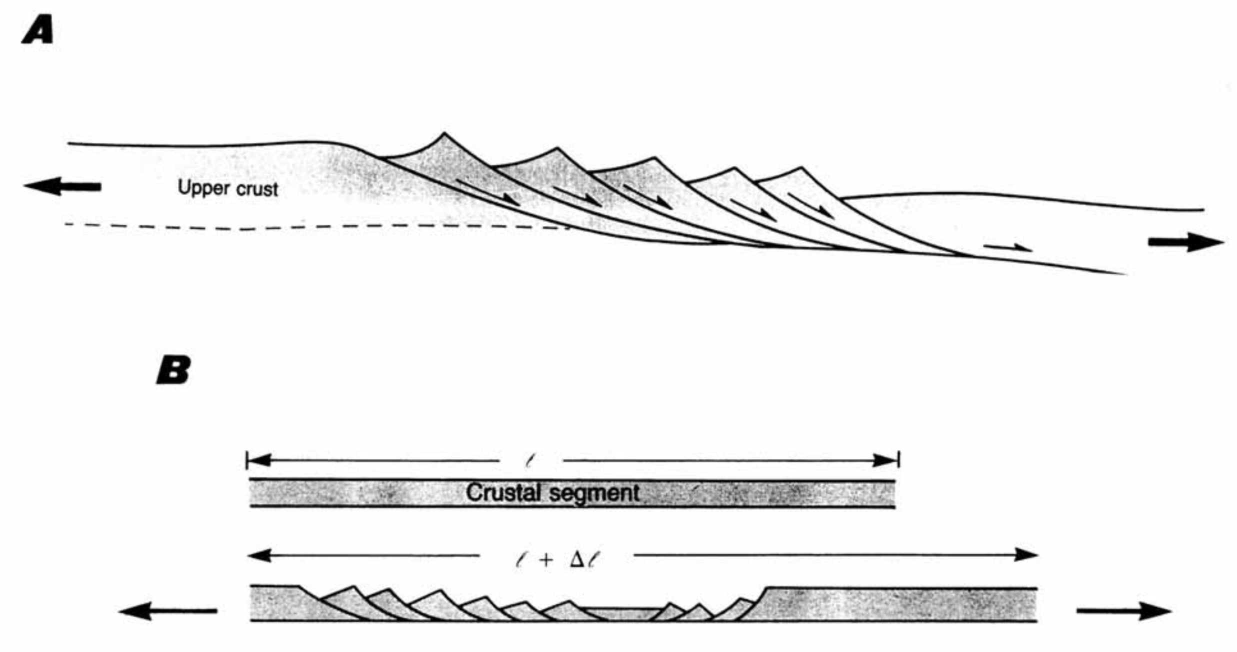


Figure 22. Profile section; steep brittle faults propagating downard, curving, and becoming horizontal at depth in the brittle-ductile transition zone. (R. D. Hatcher, Jr., 1990, A, fig. 10-15 (c), p. 190; and B fig.13-8 (c), p. 261.)

A. All faults curve in the same sense.

B. Before- and after sketch of a crustal segment in a pre-extended condition (above) and after extension and thinning. Notice that two sets of curving normal faults are present.

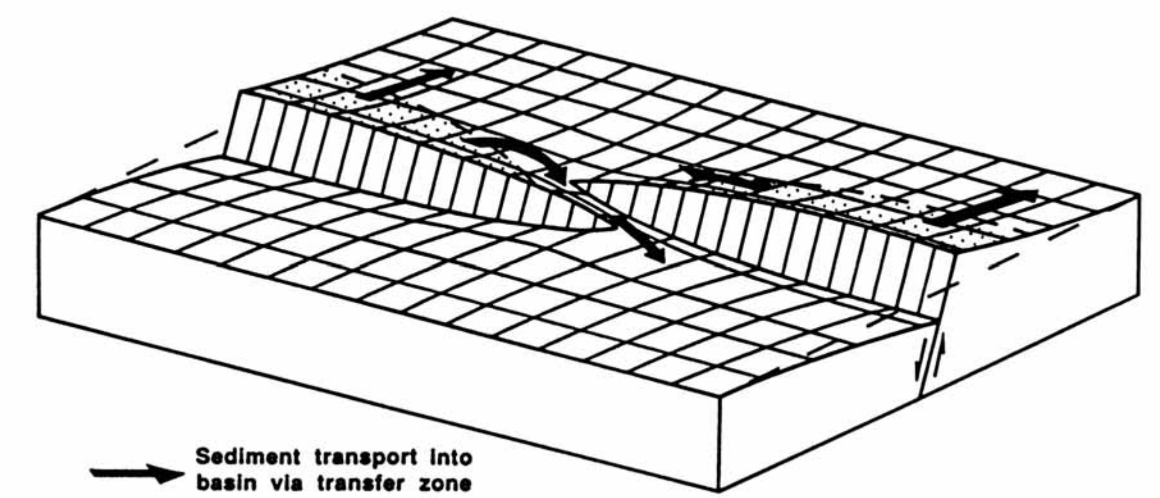


Figure 23. Schematic block diagram viewed diagonally from above showing two normal faults that are offset en ,chelon and separated by a relay ramp (=transfer zone). Black arrows on top of diagram indicate major transport directions of sediment on upthrown block. On the downthrown block, coarser synrift sediments accumulate near the ramp. (A. Roberts and G. Yielding, 1994, fig. 11.19, p. 242.)

Displacement on the curved surfaces of listric normal faults causes the formerly horizontal surface of the Earth moving downward along the fault to dip toward the fault (Figure 24). Because the angle between the fault and the surface is fixed by the relationships at the surface, as further displacement on the curved fault surface takes place, the top of the downshifted block becomes tilted to ever-steeper angles (Figure 25).

The mechanism shown in Figure 24 could cause a basin to form and to fill with sediment. Moreover, cessation of the movement on the fault would stop all the activity. When movement on the fault stopped, many strata, which were initially deposited in a horizontal orientation, would dip toward the fault. The amount of this dip would be greatest in the oldest strata and would progressively diminish to zero in the youngest beds.

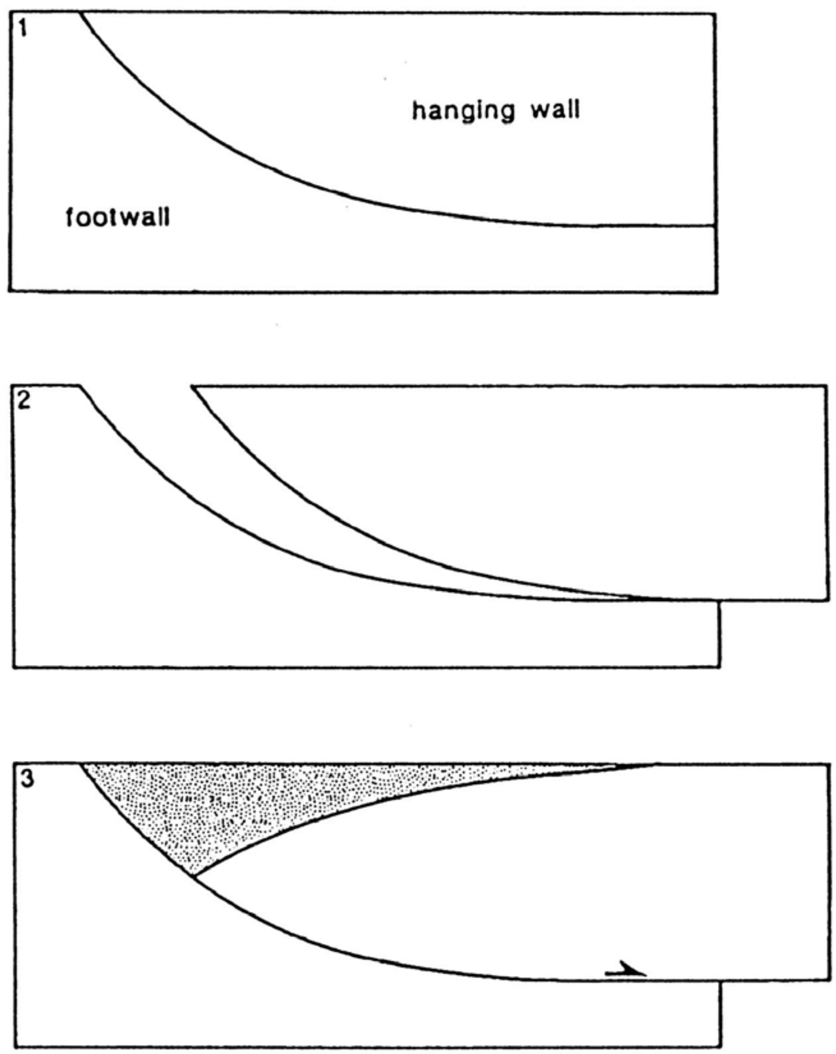


Figure 24. Wedge-shaped basin (stippled) formed by movement of a crustal block along a listric normal fault. Progressive movement causes the initially horizontal land surface to be bent downward to maintain the constant angle between the fault and the land surface (where the fault is steep) as the surface moves along the curved fault surface. (J. M. Crespi, 1988, fig. 1, p. 221.)

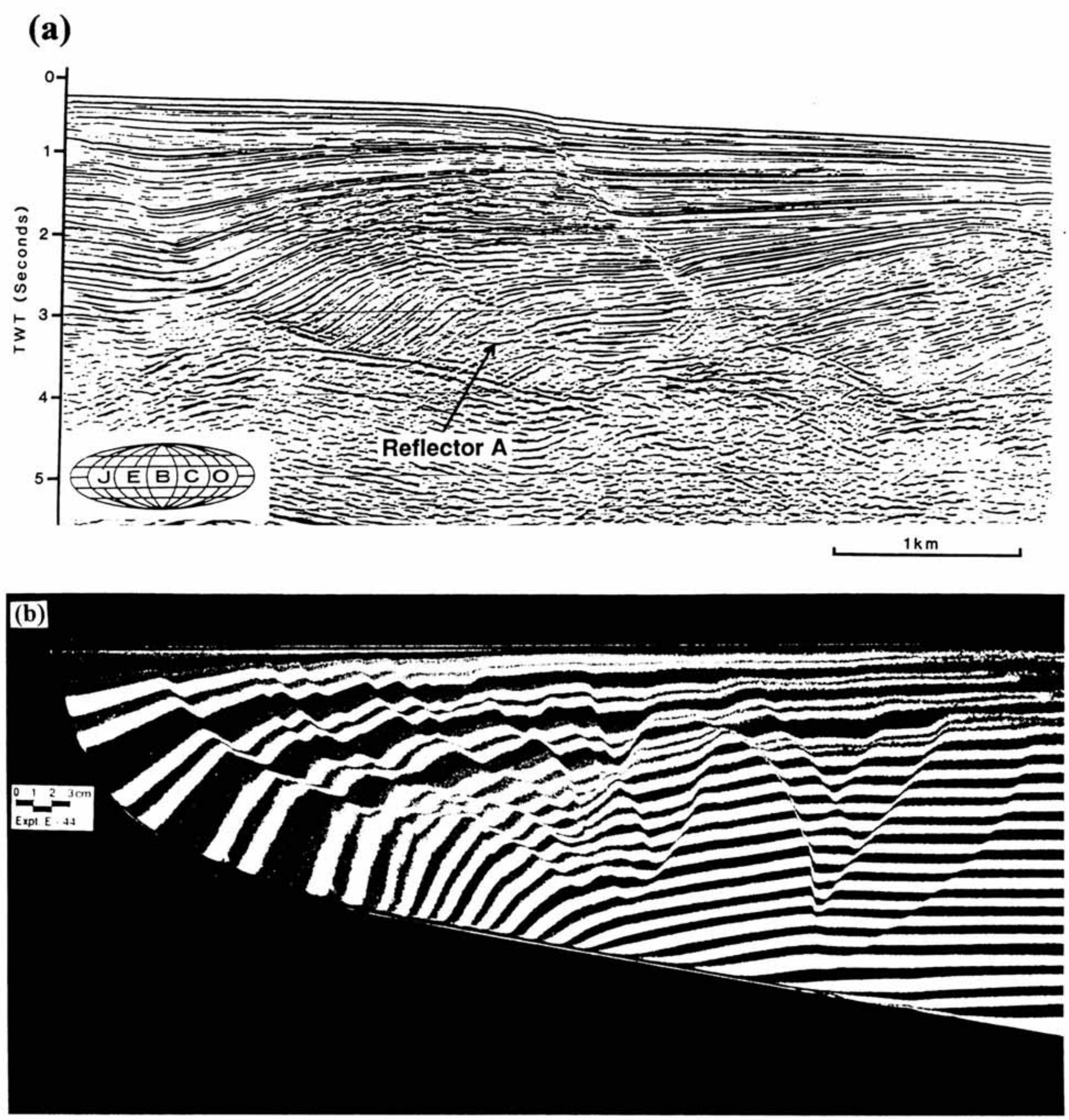


Figure 25. Effects on strata of upper block as a result of displacement along a curving normal fault. The angle between fault and strata remains constant. As the strata move downward and the fault curves, they dip toward the fault.
(a) Continuous seismic-reflection profile in Gulf of Mexico.
(b) View of sand-box model with rigid footwall block. (A. Roberts and G. Yielding, 1994, fig. 11.20, p. 243.)

Two other characteristic features of networks of normal faults, resulting from horizontal extension, that are associated with rift basins are: (1) reversal of polarity (change of direction of the strata dipping toward the active faults), a feature typically found where one normal fault dies out at a relay ramp and another fault extends beyond such a ramp; and (2) the concave-up shapes of basin floors facing concave fault surfaces. The polarity-reversal configuration results from simple extension. It does not mean that the strata, originally all horizontal, were postdepositionally arched.

The concave-up basin floor facing a concave sector of the normal fault is a configuration that results from the dying out of the displacement along a fault at both ends of the fault. The thicknesses of sediments deposited in such a basin are greatest at the point of maximum fault displacement and diminish to zero along the fault in both directions away from the point of maximum thickness.

Many of these attributes of rift basins have been displayed dramatically on the continuous-seismic-reflection profiles that Bruce Rosendahl and his associates have collected from the large lakes in the East African rift valley (Rosendahl, 1987; Rosendahl and Livingstone, 1983; Rosendahl, Reynolds, Lonben, Burgess, McGill, Scott, Lambiase, and Derksen, 1986). These concepts have been applied by many geologists to the so-called tilted-fault-block or "half-graben" variety of sedimentary basins (Leeder and Gawthorpe, 1987; Lindholm, R. C., 1978a; Manspeizer, 1988a, b; Manspeizer and Cousminer, 1976; Manspeizer, Cousminer and Puffer, 1978; Kinsman, 1975; Klitgord and Behrendt, 1979; Klitgord and Hutchinson, 1985; Klitgord, Hutchinson, and Schouten, 1988).

Does The Rift-Basin Concept Fit the Hartford Basin?

I consider that application of the rift-basin concept to the Newark basin can be classified as nothing more than a modern-day variation of the "cabbage-patch" approach to the Newark. It is an up-to-date tectonic version of H. D. Rogers' depositional scheme whereby the tilted strata are initial dips; no postdepositional tilting is required. (Many of the ideas such as this have been proposed by workers who have seen the deep seismic-reflection profiles which may show in the subsurface of the Newark basin features such as in Figure 25. I have not seen any continuous seismic-reflection profiles from the Newark basin, so my thinking is based on outcrop data only).

By virtue of numerous repetitions, the Newark-type basins have become almost synonymous with rift basins and are cited as shining examples of the products of rift tectonics. The "hidden agenda" behind this usage is that when one has incanted the magic phrase "rift basin," then all other things fall into place and our brains can go back into peaceful relaxation. Until very recently, partisans of "rift-tectonics-says-it-all" school have presumed that the machinery, which commenced operating when the Newark basin initially formed, simply kept on running, and one day, just stopped. And, when the tectonic "music" stopped being played, everything was in place. All players in the game had found seats.

My fundamental reasons for doubting that the Newark-type basins are rift basins is the field evidence in support of the view that during the episode of sedimentation, subsidence took place in such a way that the strata were deposited horizontally. In particular, the parallel relationships among the extrusive sheets does not support the concept that significant differential tilting toward the basin-marginal fault took place while strata accumulated. The only way thick strata can accumulate horizontally along an active basin-marginal fault is if this fault is vertical. The verticality must extend all along the fault. If the fault curves, the subsiding strata will acquire differential dips, greater in the older layers and less in the younger ones. Figure 26 is an example of what I regard as a flawed profile section. It shows that all the strata are parallel among themselves and to the basin floor (i. e., no differential tilting), yet portrays the basin-marginal fault as distinctly curved (concave up). This would be possible only if movement on the fault shown were entirely postdepositional. If this fault is supposed to represent the basin-marginal fault during deposition, then because all the basin-filling strata are parallel, it must not only be perpendicular to all the strata but also extend indefinitely downward at this same orientation.

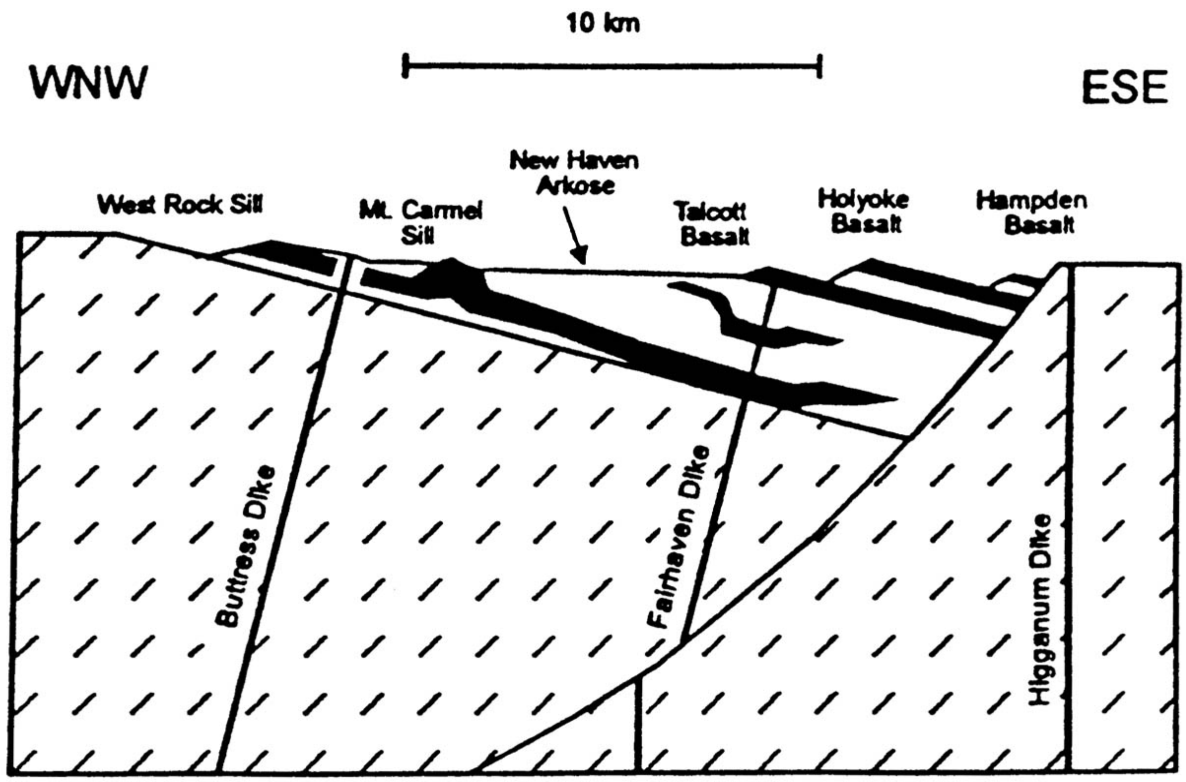


Figure 2. Cross section of Hartford Basin (after Philpotts and Martello, 1986).

Figure 26. Geologic profile-section through Hartford basin showing parallelism of all basin-filling strata (thus not related to syndepositional movement on a curved basin-marginal fault) and curvature of the basin-marginal fault. The only way this diagram is correct is if the fault shown is entirely postdepositional. That could be possible, but if so, then the resolutely planar syndpositional fault, perpendicular to the basin-filling strata, is not shown. (J. A. Kolleeny, 1996, fig. 2, p. 74.)

How About a Crestal-collapse-graben Basin?

Another possibility, not yet applied to the Newark-type basins, is that these basins are remannts of the dropped keystone block of an arch, known as a crestal-collapse graben. As mentioned, this concept would be applicable only if the faults bounding the graben are vertical.

Obviously, I have not worked through all of the ramifications of the suggestion that the Newark basin resulted from relative regional elevation rather than lithosphere stretching. The plate-tectonic setting of a crestal-collapse-graben basin would be one of epeirogenic uplift, presumably related to phase changes and the thermal situation down below. The whole point is that such a basin is not in any way directly connected to a new ocean.

Another salient point, and one not generally recognized, is that the tectonic activity which ended the life span of the Newark-type basins differed significantly from whatever tectonic activity caused the basin to form and to fill with sediments. In other words, something changed drastically to end the period of sediment accumulation and to cause the formerly horizontal strata to acquire their present non-horizontal attitudes.

So much for gum-flapping and arm waving. On to today's objectives.

OBJECTIVES

1) To study the basal contact of the New Haven Arkose and the kinds of metamorphic rocks forming the floor of the Hartford Basin.

2) To examine paleosol caliche in the New Haven Arkose and study the contact-metamorphic effects on the caliche along the walls of mafic dikes.

3) To examine pillows--the products of the extrusion of hot lava under a cover of water.

4) To examine the characteristics of the Newark sedimentary strata and to notice the contrast between sediments deposited well away from the basin-marginal fault along the SE basin margin and those deposited close to this basin-marginal fault.

5) To study the composition of boulders in the basin-marginal rudites (general name for any coarse sediment composed chiefly of gravel-size debris, i.e., coarser than 2 mm).

6) To study the evidence for postdepositional faults and the relationship between some of these faults and gaps in Saltonstall Ridge.

7) To examine the evidence for the presence of the Talcott Formation along the basin-marginal fault and to observe a distinctive volcanic breccia.

8) To visit the Eastern Uplands and examine the pink granitic rocks at Stony Creek and the light gray granitic rocks at Lighthouse Point.

LIST OF LOCALITIES TO BE VISITED

(Stop locations are shown on the road map, Figure 27).

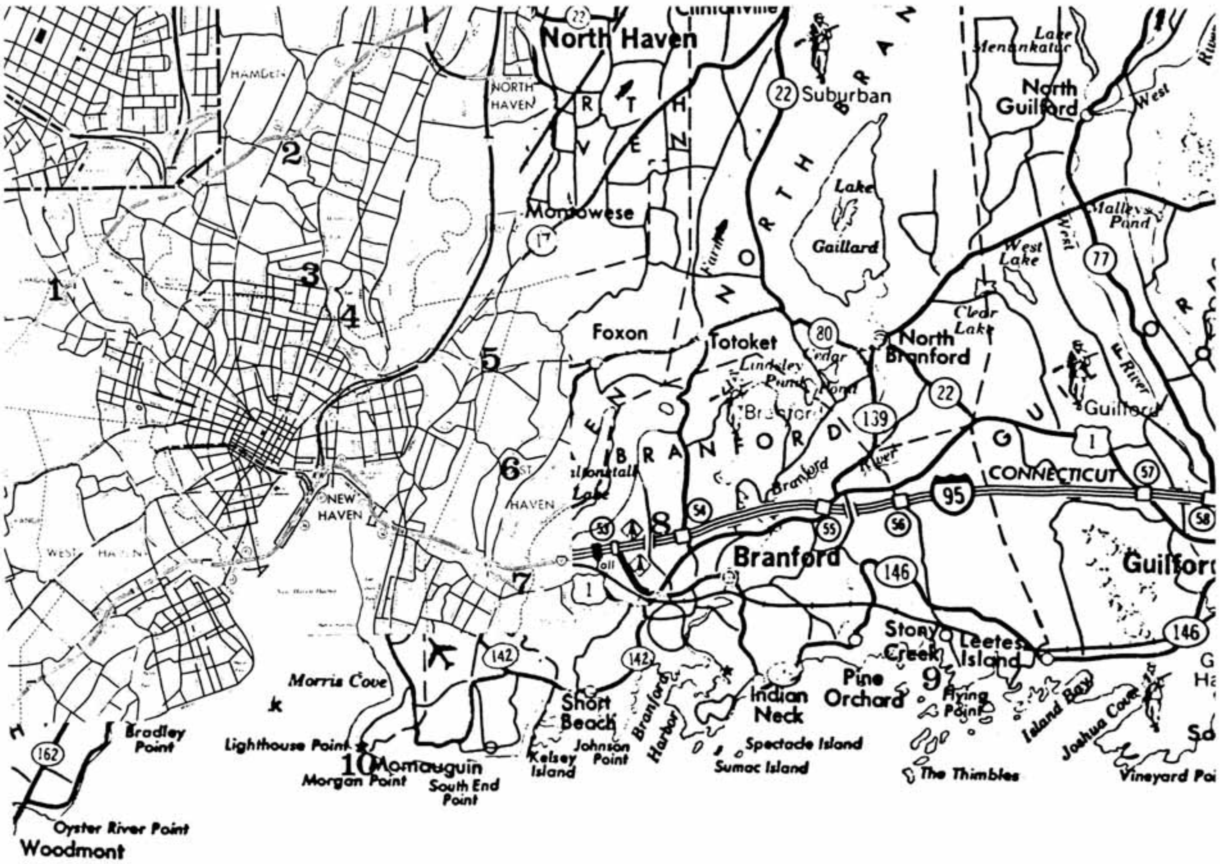


Figure 27. Road map showing locations of Stops 1 through 10. (Official highway map of Connecticut; two joined-together segments.)

Stop 1 - Nonconformable basal contact of Newark Supergroup, Amity Shopping Center, Woodbridge, CT (near Interchange 59, Wilbur Cross Parkway), New Haven quadrangle.

Stop 2 - New Haven Arkose, roadcut on Wilbur Cross Parkway at Interchange 60, CT Route 10, Dixwell Avenue, New Haven quadrangle.

Stop 3 - Contact of Mill Rock dike and New Haven Arkose, Whitney Avenue near corner of Armory Street, New Haven, CT, New Haven quadrangle.

Stop 4 - LUNCH; Top of East Rock, New Haven quadrangle.

Stop 5 - Contact-metamorphosed New Haven Arkose, roadcut on Route 80, northeastern New Haven (Branford quadrangle).

Stop 6 - Talcott Formation, pillowed member, near restaurant (Weeping Willows in 1960's; same name in 1996?), off Laurel St., East Haven, CT (Branford quadrangle).

Stop 7 - Shuttle Meadow Formation, Holyoke Formation, East Berlin Formation; faults and gaps near S end of Lake Saltonstall, East Haven, CT. (Branford quadrangle).

Stop 8 - Talcott Formation in fault blocks adjacent to basin-marginal fault, Todds Hill Rd. overpass, W. of Interchange 54 on Connecticut Turnpike, Branford, CT. (Branford quadrangle).

Stop 9 - Stony Creek Granite, Stony Creek village (Branford quadrangle).

Stop 10 - Lighthouse Granitic Gneiss, Lighthouse Point, New Haven (Woodmont quadrangle).

DRIVING DIRECTIONS

NYAS to 5th Ave, S to 62nd St., E to FDR Drive northbound. Cross East River at Willis Ave. bridge, turn L to enter Major Deegan Expressway northbound. Off at Cross County Shopping center to pick up participants from Westchester Co.

Go R. out of Cross County Shopping center, and turn R again for eastbound Cross County Parkway, Hutchinson River Parkway, Merritt Parkway.

Merritt Parkway/Wilbur Cross Parkway to Woodbridge, CT. Leave Wilbur Cross Parkway at Interchange 59, just before West Rock Tunnel. Exit ramp ends at Litchfield Turnpike (CT Route 69). Turn L, drive under Parkway, and in 0.1 mi., turn L into Lucy Street. In one block, Lucy St. ends against Amity Road (CT Route 63). Turn L onto Amity Road and R into Amity Shopping Center for STOP 1.

Leave Amity Shopping Center; turn R on Amity Road and drive under Parkway. In 0.2 mi, at intersection with Litchfield Turnpike, make sharp L into Litchfield Turnpike (CT Route 69), and in 0.2 mi, turn R into entrance ramp for Wilbur Cross Parkway (in direction of Hartford). Join parkway and drive through West Rock Tunnel. In mi. leave Parkway at Interchange 60, exit ramp on R for Dixwell Avenue (CT Route 10). Park along exit ramp and walk back to cut on SE side of Parkway for STOP 2. New Haven Arkose with greenish calcite caliche (calcrete).

Continue on exit ramp to Dixwell Avenue. Turn L onto Dixwell Ave. (CT Route 10). Follow it for 2.4 mi to intersection where CT Route 10 goes R into Arch Street, turn L into Morse Street. In 0.5 mi, turn L (to N) onto Winchester Avenue (so named for the Winchester Repeating Arms Co. factory ca. 0.5 mi. to the S from Morse St.). Continue N on Winchester Ave. to dead end at Mill Rock Road. Turn R onto Mill Rock Road and follow it 0.65 mi. to its E end (Armory Street). Start looking for a place to park for STOP 3 (on Whitney Avenue just N of Armory Street).

Return to van; turn R into Whitney Avneue, and take first street on L (East Rock Park). In 0.2 mi, turn L onto East Rock Road, cross Mill R. and turn L on Farnum Drive (drive to top of East Rock if the road is open) for Lunch Stop 4 at top of East Rock. (Plan B, to be announced, if drive to top is closed.)

Return to bottom on Farnum Drive; at end of Orange Street, Farnum Drive becomes English Drive. Drive to end (onto Grace St., and junction of State Street (US Route 5) and Middletown Avenue. Cross State Street, take Ferry Street-Middletown Avenue (CT Route 80) bridge over RR tracks. Just over this bridge, Middletown Avenue goes to the L (staying parallel to and just N of I-91). Following Middletown Avenue, cross Quinnipiac R., go under 2 RR bridges and beneath I-91 at Interchange 8. Just after passing beneath I-91, Middletown Avenue goes to the L and CT Route 80, the road we want, becomes Foxon Blvd. In 0.5 mi, enter Branford quadrangle, then immediately cross Quinnipiac Ave. and look for parking place, possibly along Old Foxon Road on R. Contact-metamorphosed New Haven Arkose, Stop 5 in cuts on N. side of Ct. Route 80.

Reboard vans, turn R into Old Russo Avenue and drive 0.75 mi. to end. Canvass situation with respect to cuts in New Haven Arkose along old trolley line just N of T intersection where Old Russo Avenue ends against Strong Street. Possible STOP 5A.

Turn R into Strong Street. In 0.3 mi., curve 90° R, in 0.15 mi, bends around to L past Camp Hubinger. In another 0.35 mi, dead end against Grannis Street. Turn R onto Grannis Street. In 0.1 mi, curve to L. In 0.2 mi, X intersection, turn L into Laurel Street. In 0.2 mi, look on L for what used to be the site of the former Weeping Willows Restaurant. What this place is now is anybody's guess; there's no more Weeping Willows Restaurant and the East Haven Chamber of Commerce never called back to say what it has become. Slight pause while the trip leader goes inside to request permission to park out back and to look at the rocks beyond. STOP 6, Talcott Formation,

Leave parking lot by turning L into Laurel Street. Drive to S end of Laurel St., Use High Street over RR and Connecticut Turnpike. In 0.35 mi, turn L into Main Street, East Haven. In 0.25, Main Street bends L. In 0.35 mi, complex intersection; turn L to cross over US Route 1. Cross over and park van. Walk back to roadcut on N side of US Route 1 for STOP 7.

Walk to Railroad cut; van to move closer.

Reboard van, turn around, return to US Route 1 and turn L (eastward). Continue E on Boston Post Road for 2.0 mi to jct US Routes. 1 and 1A; bear L to take US 1A to the E. After 0.5 mi, turn sharply L onto Todds Hill Road (L-hand of V junction with Cedar Street on R) and drive 0.35 mi to cross above Connecticut Turnpike. Park on N side of bridge over Turnpike for STOP 8.

Reboard van, turn around; retrace route to V junction at US Route 1A. Without entering US 1-A (if possible), turn sharply L into Cedar Street, drive 0.15 mi. N and turn R into E-bound Connecticut Turnpike at Interchange 54. The rocks in the cuts along the entrance ramps are part of the Eastern Uplands; we have crossed the basin-marginal fault (which is under Cedar Street).

Drive 2.8 mi. E to Interchange 56. Leave Turnpike at Interchange 56, Leetes Island Road. Drive 2.0 mi. S to Stony Creek to see Stony Creek Granite (STOP 9)

Reboard van, retrace route to Connecticut Turnpike, Interchange 56. Enter W-bound lane and drive to East Haven. Exit from Turnpike at Interchange 50, Townsend Avenue and New Haven airport. At top of ramp, turn L, cross over Turnpike and go south on Townsend Avenue. Continue past Forbes Bluff to Morris Cove. Turn R onto Lighthouse Road. Just after entering Lighthouse Road, cross basin-marginal fault and onto pre-Newark rocks. Follow to end of Lighthouse Road at Lighthouse Point Park for STOP 10.

DESCRIPTIONS OF INDIVIDUAL LOCALITIES ("STOPS")

STOP 1 - Base of Newark Supergroup in contact with Milford Chlorite Schist, Amity Shopping Center. [UTM Coordinates: 668.55E / 4577.83N, New Haven quadrangle.]

You're on your own.

STOP 2 - New Haven Arkose and caliche carbonate (green) cut on Wilbur Cross Parkway at Interchange 60. [UTM Coordinates: 673.81E / 4581.02N, New Haven quadrangle.]

Krynine (1950) measured a section here when the cut on the Parkway was fresh. In 1958, JES spotted the green calcareous nodules and interpreted them as probable caliche. Hubert (1977, 1978) has published the results of his careful petrographic examination of the caliche/calcrete. We will forego an opportunity to see spectacular exposure of caliche carbonates, etc., in the New Haven Arkose on Mt. Carmel Connector Road. Pedogenic carbonates are important indicators of a former semiarid climate (Hubert 1977, 1978). At Stony Brook investigations are in progress on the possibility of using Pb/U dating methods on syndepositional uranium (Wang, Rasbury, Hanson, and Meyers 1996) and on the contact-metamorphic effects on caliche near dikes (Kolleny, 1996).

STOP 3 - New Haven Arkose in contact with N wall of Mill Rock dike. [UTM Coordinates: 674.35E / 4578.07N, New Haven quadrangle.]

You're on your own.

STOP 4 - Top of East Rock. On a clear day, the view from up here is spectacular. [UTM Coordinates: 675.19E / 4577.09N, New Haven quadrangle.]

You're on your own.

STOP 5 - New Haven Arkose in contact with one of the Foxon dikes. [UTM Coordinates: 678.07E / 4576.29N, Branford quadrangle.]

You're on your own. Hope this figure helps!

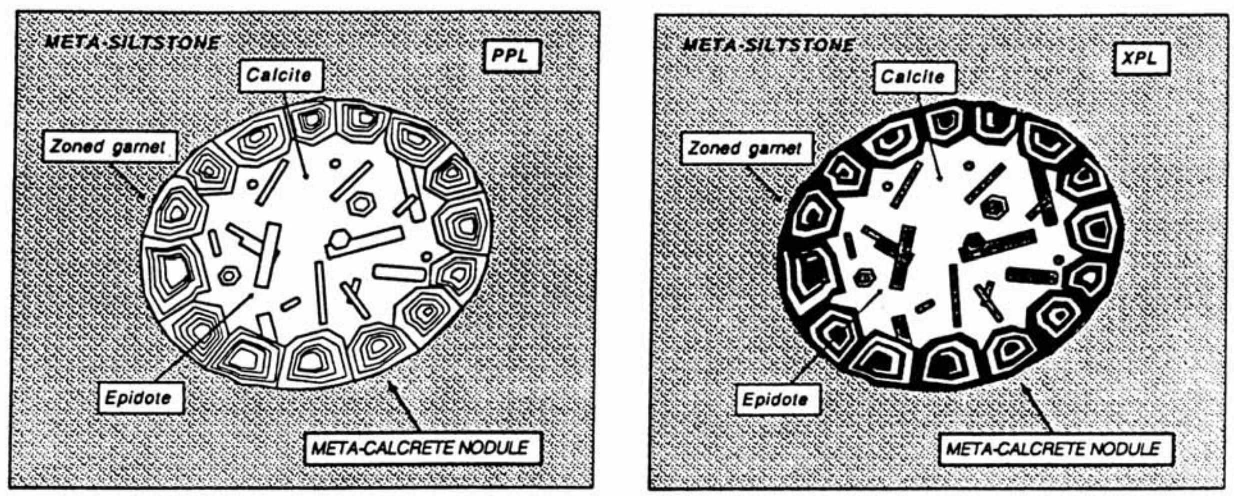


Figure 28. Sketch of enlarged view of petrographic thin section cut through a meta-calcrete nodule within a metasiltstone, New Haven Arkose adjacent to a dike at Dee's Quarry, Mount Carmel. PPL, view in plane-polarized light; XPL, view in cross-polarized light. (J. A. Kolleeny, 1996, fig. 3, p. 76)

STOP 6 - Pillowed Talcott basalt, hillside E of what formerly was the Weeping Willows Restaurant, E of Laurel Street, East Haven. [UTM Coordinates: 678.11E / 4574.60N, Branford quadrangle.]

At this locality, the distance from the basin-marginal fault is 2 miles. (3.2 km.) The strata strike N15°E and dip 30° SE on a limb of the Saltonstall syncline. The part of the Talcott exposed here is the base of the pillowed- and brecciated member. The correct classification of the underlying pebbly coarse sandstone is still a puzzle. The answer depends on whether other Talcott flow units are present below the sandstone. If so, then these strata belong in the middle sedimentary member. If not, then these strata presumably belong at the top of the New Haven Arkose.

This exposure resulted from excavation of till and the effects of subsequent rainstorms. The pillows of the pillowed- and brecciated member of the Talcott Formation are strikingly displayed. The effect of a Pleistocene glacier on the pebbly sandstone is also well displayed here. This is a good spot for comparing the scratches and striae created by a glacier with the marks made by the large power shovel used in excavating the till.

STOP 7A - Cut on N side of US Route 1, East Haven, at junction with western end of loop made by CT Route 142. This is the southern of two large gaps in Saltonstall Ridge. [UTM Coordinates: 679.10E / 4571.51N, Branford quadrangle.]

Formation: Shuttle Meadow
Stratigraphic position: Highest strata exposed are approximately 200 ft below top, but exact location is not known.
Distance from border fault: 0.85 mi.
Particle sizes of sedimentary strata: silt up to boulders.
Attitude of strata: N 43° W, 55° NE.
Structural setting: Totoket syncline; limb offset by numerous faults striking nearly E-W; gaps have formed as a result of fault displacement of the resistant Holyoke Formation underlying the ridge.

A tape-and-compass traverse of this cut indicates that about 190 ft of strata are present; there are numerous small faults, but nevertheless the succession seems to be fairly straightforward. The lower 80 ft are interbedded sandstone and siltstone with a few pebbly layers. Two prominent conglomerates are present: a unit 20 ft thick at 80 ft above the base of the exposure, and a unit 18 ft thick at 130 ft above base of the exposure. The sandstones at the top of the exposure may correlate with those exposed north of the New Haven Railway tracks in the next gap to the north, but this is not certain.

A count of 400 pebbles in the lower (20-ft) conglomerate unit showed the following distribution of long diameters:

Names of particles	**Limiting diam. (mm.)**	**Proportion (per cent)**
Fine pebbles	4 to 8	2.5
Medium pebbles	8 to 16	16.8
Coarse pebbles	16 to 32	36.7
Very coarse pebbles	32 to 64	29.4
Small cobbles	64 to 128	13.5
Large cobbles	128 to 256	1.0

The kinds of rocks were distributed as follows:

Rock type	**Proportion (per cent)**
Quartzite	60
Granitic rocks and pegmatites	20
Schists	8
Limestone and carbonate rocks	6
Sandstones (?)	4
Gneisses	2

The noteworthy feature of the composition of the clasts is the large proportion of quartzite (presumably from the Plainfield Formation) and the presence of limestones and carbonate rocks. These earbonate rocks form disks and blades; several kinds are present and all were derived from nonmetamorphosed source rocks. The whereabouts of such source rocks in the Eastern Highland province is a complete enigma. One possibility is that they were derived from the carbonate rocks of the Lower Jurassic Talcott and basal Shuttle Meadow formations. If so, then these Jurassic carbonate rocks were deposited in lakes that extended at least locally across the basin-marginal fault. It is not known whether any Jurassic carbonate rocks are present on the fault block to be seen at Stop 8.

The exposures in this cut and those in the cuts in the next gap to the north are instructive in that they completely disprove the idea, championed by W. M. Davis (1898), that gaps resulted from zones of weakness along faults. Davis mapped one fault along the axis of each gap; he thought the strike of the gap-forming faults is NE-SW.

Figure 29 shows my interpretation of the faults. Although many of the details may be difficult to see clearly in the black-and-white drawing, the important points are obvious. In particular, each gap has resulted from the dislocations on four faults striking N85°E, not from one fault striking NE-SW, as Davis supposed.

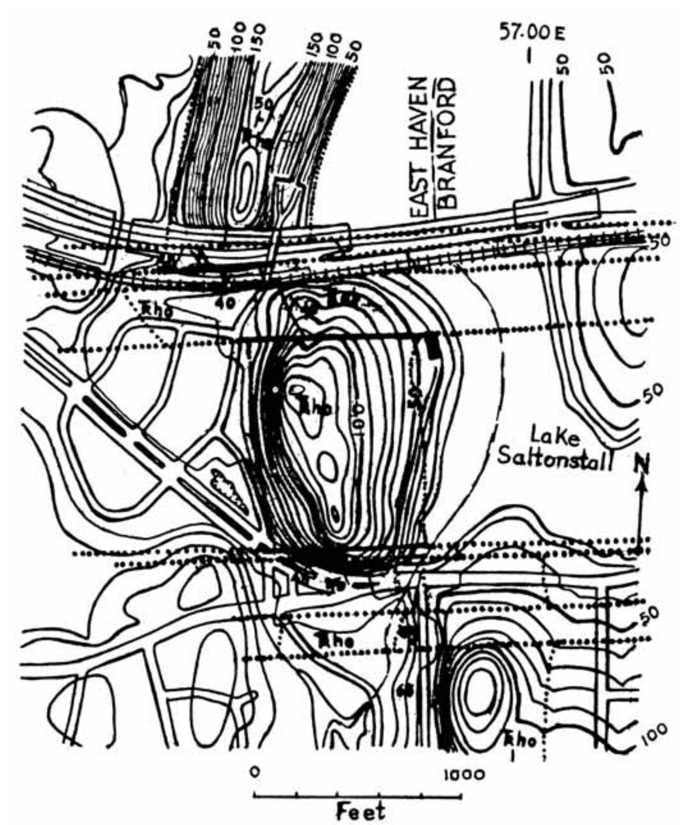


Figure 29. Geologic sketch map of faults- and gaps in Saltonstall Ridge, East Haven, CT (Branford 7.5-min. topographic quadrangle map of U. S. Geological Survey. (J. E. Sanders, 1970, fig. 5, p. 12; drawn by Bill Osborn.)

Two faults can be pinpointed in the US Route 1 cut; these are shown by the solid lines in Figure 29. The perpendicular distance between these two faults (based on tape-and-compass survey) is 57 ft. Along the northern of these two faults the base of the Holyoke Formation has been displaced from a presumed position at road Ievel (on side road west of the hill) to a point on the hillside where it dips 45°. Assuming a 45° dip on both sides of the northern fault, then the vertical component of slip is 65 ft relatively up on the S side.

The southern of these two faults is by far the larger. Along it, the base of the Holyoke Formation has been displaced at least 450 ft eastward south of the fault. Assuming a dip of 55°, then the vertical component of slip is 643 ft relatively up on the S side. The base of the Holyoke Formation on the block S of this fault has not been precisely located. Borings for the highway where it crosses the outlet of Lake Saltonstall reported only conglomerate- and sandstone bedrock. My best guess is that the base of the Holyoke Formation lies nearly opposite the line formed by the top of this formation on the block N of the two faults being described. The other two faults shown S of US Route 1 are based on indirect evidence. No direct confirmation is available for the presence of the Holyoke Foration in the lowland south of the highway (as shown on the map); it is thought to be there because only sedimentary strata are present on the N slope of the knoll at the S edge of Figure 29.

STOP 7B - Cuts on AMTRAK Railway and Connecticut Turnpike, East Haven, in an artificial gap west of Saltonstall Lake, the northernmost of the two large gaps in Saltonstall Ridge. [UTM Coordinates: 679.06E / 4571.95N, Branford quadrangle.]

Formations: Shuttle Meadow, Holyoke, East Berlin.
Stratigraphic positions: Shuttle Meadow (base and top 174 ft).
Holyoke (most of it, including base and top)
East Berlin (basal few feet)
Distance from border fault: 1.25 mi (2.0 kilometers)
Particle sizes of sedimentary strata: silt, sand, and fine pebbles.
Attitude of strata: (varied; in cut on north side of New Haven Railway tracks: N20°W, 40° NE).
Structural setting: faulted limb of Saltonstall syncline. The large gap accommodating the railway and the Connecticut Turnpike is, evidently, the work of man (sic). Percival (1842) mentions that the crest of Saltonstall Ridge extended unbroken from the gap through which Saltonstall Lake overflows (Stop 7A) to its northeastern extremity. The location of one of the faults is known exactly and the positions of the other three can be bracketed within narrow limits.

To begin with, the Shuttle Meadow strata in the railway cut consist largely of sandstone and siltstone in beds 1 to 3 ft thick; a tape-and-compass traverse indicates 174 feet of strata are present from the bridge abutment on the north side of the tracks to the western limit of the exposure. The contact between Shuttle Meadow sandstone and Holyoke basalt was exposed during construction of the bridge in the middle of the nineteenth century; the stones of the bridge pier conceal it now.

The top of the Holyoke is present just east of this bridge, on both the N side and S side of the tracks. The horizontal distance between the base of the Holyoke and the top of the sheet is 110 ft; assuming a dip of 45° this indicates a vertical component of slip equal to about 700 ft. About 1 ft above the base of the overlying East Berlin Formation is a limestone bed 1 ft thick; it is visible in the cut on the south side of the railway and east of the bridge.

The bridge over the railway, therefore, spans the fault marking the north side of a graben 750 feet wide. The Holyoke Formation in the graben is largely covered. The Holyoke-East Berlin contact can be followed part way up the hill to the fault on the south side of the graben. Along this fault the East Berlin formation has been shifted 560 feet eastward to the pump house along the west shore of Lake Saltonstall; with dip of 45° (and assuming strike is perpendicular to the faults, which is not quite true), the vertical component of displacement is also 460 ft.

By crossing over the tracks on the bridge and turning left onto the small hill separating the railway and the Connecticut Turnpike, it is possible to pinpoint a fault separating the Holyoke igneous rock and Shuttle Meadow sandstone and to see the contact at the base of the Holyoke Formation. The fault extends down the center of this small hill; it is only 31 ft north of the fault at the N side of the graben we have just seen. Along the fault at the north side of this thin fault block, the base of the Holyoke Formation has been shifted relatively downward on the N so that it is displaced from the bridge abutment to the cut along the south side of the Connecticut Turnpike (16.32 N - 56.84 E). The indicated vertical component of slip is 172 ft.

Still-another fault lies somewhere under the Conecticut Turnpike: along it the base of the Holyoke Formation has been shifted westward to the base of Saltonstall Ridge. A tape-and-compass traverse of the Holyoke Formation along the cut north of the Turnpike yielded a thickness of 434 ft, with neither base nor top exposed. This is 34 ft more than the thickness Longwell found in the New Haven Water Company's tunnel through Saltonstall Ridge at the north end of Saltonstall Lake (Figure 3).

In summary, the four faults that strike E-W through Saltonstall Ridge at the gap cut for the railway and turnpike have resulted in a general left-lateral offset of the ridge, just as in the gap followed by US Route 1. In each case, the topographic low point evidently has resulted from the effects of the shift of the of the resistant sheet of extrusive rock. The natural gap followed by US Route 1 has cut through at the point where the base of the resistant layer has been shifted opposite its top on the opposite side of the fault.

STOP 8 - Roadcuts in Branford, along Connecticut Turnpike W of Todds (Cherry) Hill Road overpass and at Interchange 54. [UTM Coordinates: 681.92E / 4572.54N, Branford quadrangle.]

From the bridge carrying Todds Hill Road over the Connecticut Turnpike three rock faces are visible (Figure 30):

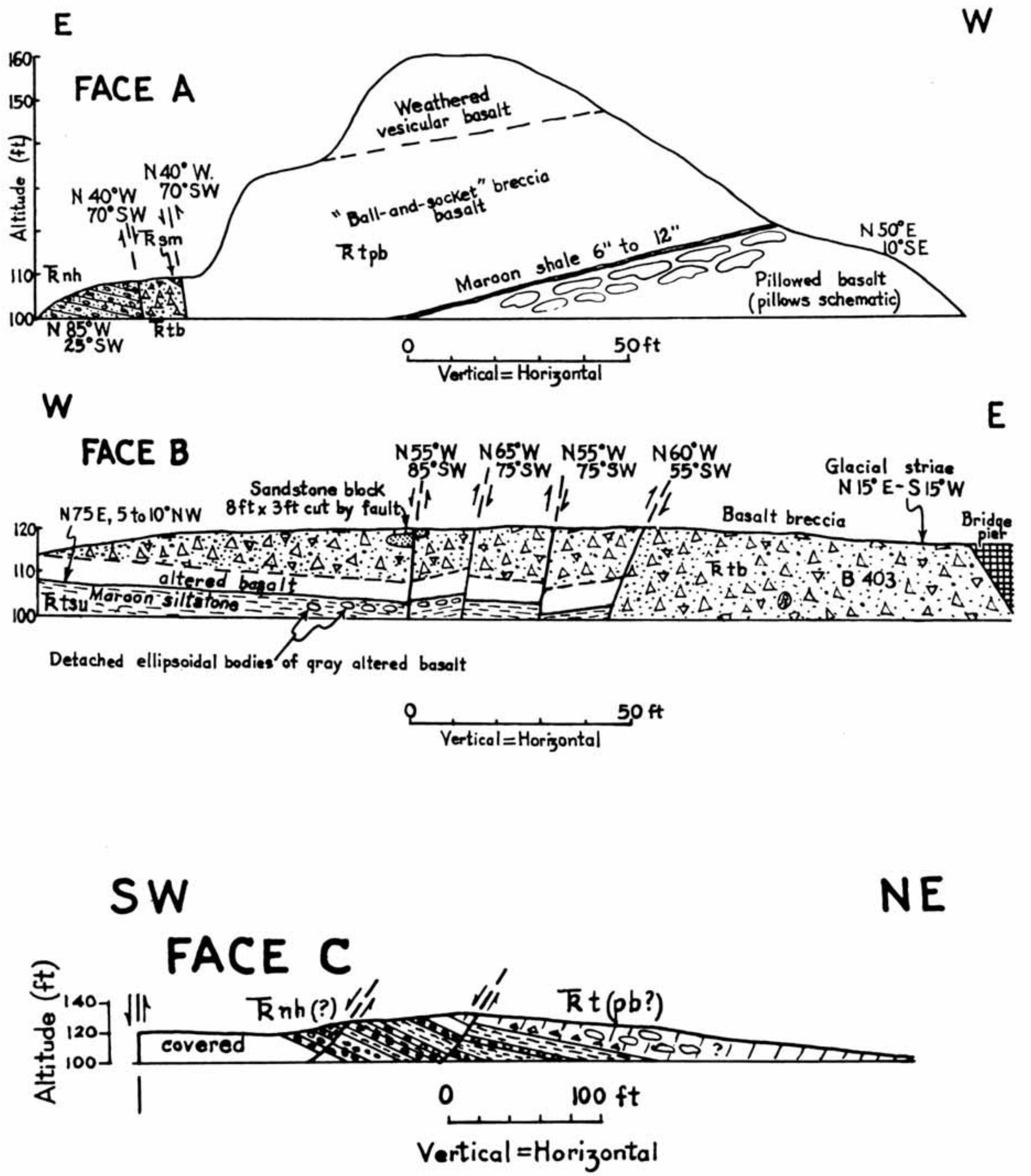


Figure 30. Sketches of the three roadcut faces at Stop 8, Todds Hill Road overpass, just W of Interchange 54, Branford, CT. (J. E. Sanders, 1970, fig. 2, p. 5 and top part of fig. 3, p. 6.)

Face A (16.51 N - 57.94 E) South side of turnpike, W of Todds Hill Road overpass;
Face B (16.55 N - 57.98 E) North side of turnpike, W of Todds Hill Road overpass;
Face C (16.56 N - 58.02 E) North side of westbound approach road of Interchange 54 onto Connecticut Turnpike.

These three rock faces expose volcanic rocks belonging to a linear belt of extrusive rocks paralleling the basin-marginal fault and extending NNE for 0.95 mi. (1.55 km), from the basin-marginal fault at the intersection of US Routes 1 and 1A, west of Branford Center (16.53 N - 57.84 E) to a point 0.07 mi. (0.1 km) N of the intersection of Todds Hill Road and a short road leading to Brush Plain Road (16.65 N - 57.97 E).

Percival (1842, p. 325) designated this belt as the "Second Posterior Range" (p. 2 of his map). Since the time of W. M. Davis (1898, p. 128; fig. 31) most geologists (exception Rodgers 1985, following Sanders' results) have assigned the volcanic rocks of this belt to the upper extrusive sheet (Hampden Formation of modern terminology; lower part of Figure 31). Davis inferred that the volcanic rocks had been dragged upward by movement along several smaller faults paralleling the basin-marginal fault. In the absence of any other compelling evidence to the contrary, this interpretation satisfied the dictates of the rule of simplicity: if there must be a fault, prefer the alternative that requires the least displacement. The Davis cross section of the 1898 report was not drawn to scale; I have tried to re-create it along a profile based on the modern topographic map of the Branford quadrangle (lower part of Figure 31). Davis' geologic map did not show as many faults as he sketched on his cross section.

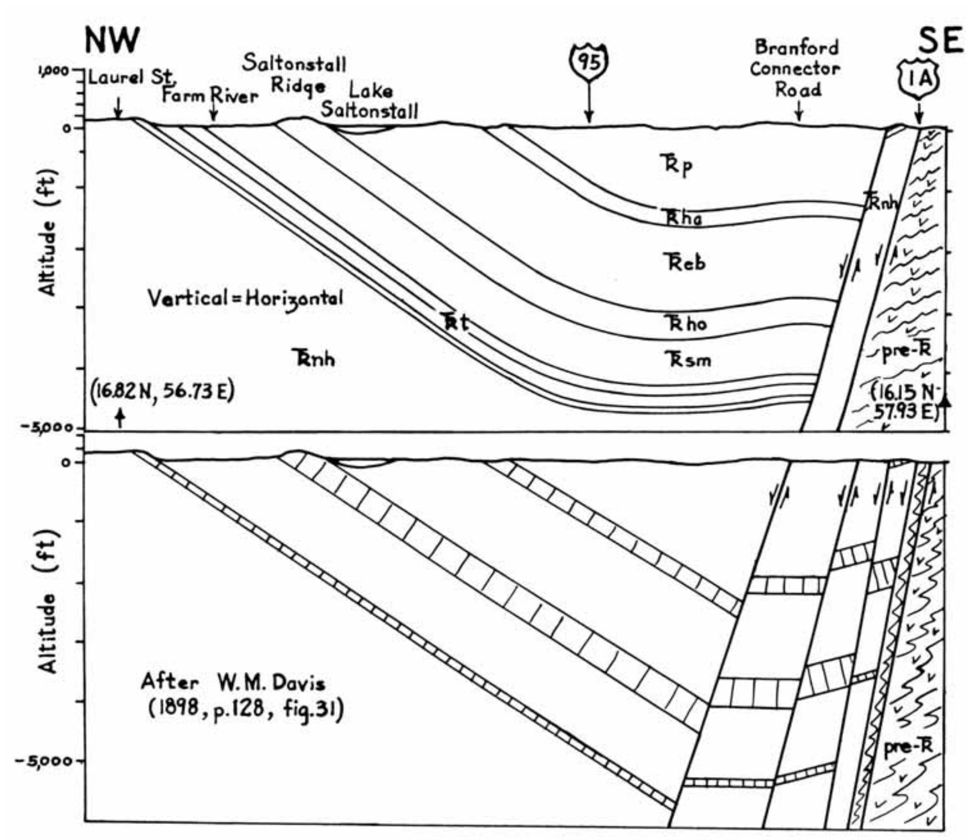


Figure 31. Geologic profile-sections along axis of Saltonstall transverse syncline, Branford 7.5-min. quadrangle, CT, according to two interpretations. Upper section shows the upfaulted extrusive rock adjacent to the basin-marginal fault to be the Talcott Formation. Lower section shows upfaulted extrusive rock to be part of the Hampden Formation (after W. M. Davis, 1898, fig. 31). (J. E. Sanders, 1970, fig. 4, p. 7.)

Assignment of the volcanic rocks of this belt to the Hampden Formation implies a minimum displacement on the fault lying to the west of 1,400 ft (420 m). According to my stratigraphic interpretation, the volcanic rocks belong to the Talcott Formation. Assignment of these volcanic rocks to the Talcott Formation increases the number of faults from 1 (or 3, according to Davis) to at least 10, and increases the stratigraphic displacement on the fault lying to the west by 3,000 ft (920 meters) to a value of 4,400 ft (1,340 meters).

Face A:

The rocks exposed in the main part of Face A are nearly flat lying and include a lower pillowed basalt, at least 25 ft (8 m) thick with base not exposed, a sedimentary parting, 6 to 12 in. (15 to 30 cm) thick, and an upper brecciated- and vesicular basalt at least 55 ft (17 m) thick with top eroded. Careful examination discloses that two thin sedimentary partings are present (not shown on the sketch of Figure 30). These are interpreted to be the result of faulting of a single sedimentary parting. A fault parallel to the face is inferred to have dropped the north side by a few meters, thus repeating the sedimentary parting. These volcanic rocks are assigned to the pillowed- and brecciated member of the Talcott Formation, which elsewhere [for example, Connecticut Turnpike cuts through Mullins Hill west of Saltonstall Ridge (16.40 N - 56.66 E)] consists of two sheets of extrusive rock, a lower pillowed sheet an an upper sheet that contains columnar joints and/or a distinctive breccia that W. L. Russell (l922 ms.) named the "ball and socket" (sic) breccia. A more-accessible face exposing the "ball and socket" (sic) breccia is located at the rear of the drive-up hamburger stand at the junction of US Route 1 and 1A (16.53 N - 57.84 E). The "balls" evidently are tiny pillows or broken pillows; the "sockets" are formed by thin layers of clay, silt, and fine-textured tephra.

Face B:

The west end of Face B displays the contact between maroon siltstone and brecciated basalt. The siltstone is noteworthy because this close to the basin-marginal fault such fine-textureed stata are rare. The best explanation to account for the deposition of such fine-textured strata in localities where coarse fan debris generally prevails suggests that within the lowland receiving sediment during Early Jurassic time, large, deep lakes appeared and that their waters submered the fans and their shores lapped against the marginal highland block to the east (Sanders, 1968).

Isolated within the upper 2 ft of the siltstone are ellipsoidal bodies of gray, altered basalt, 6 in. to 1 ft in longest diameter.

The basal 4 to 5 ft of the volcanic unit consists of altered volcanic rock mixed with maroon sediment. Higher up, the volcanic rock is not altered but includes angular blocks of basalt in a matrix that includes coarse sedimentary debris and a few large "erratics" of sedimentary- and metamorphic rocks. Toward the top of the middle of Face B is the largest of these "erratic" blocks. Here, a platy chunk of feldspathic sandstone, 8 ft long and 3 ft thick, has been cut through by a fault having a displacement of 2 ft up on its east side.

At the E end of Face B the distinctive breccia of this member extends to road level. The largest block of basalt seen here measured 2 by 3 ft; the dimensions of many are 1 by 2 ft, but most of them measured 6 to 8 in. across. All blocks show chilled margins with the coarse sandy matrix.

On the top surface of breccia just west of the bridge pier are glacial striae oriented N15°E - S15°W.

Face C:

Face C displays both sedimentary- and volcanic strata dipping 30° to 35° eastward. The sedimentary strata include boulder-bearing conglomerates, in layers 2 to 10 ft thick, intebedded with pebbly- and shaly poorly sorted silty sandstone (coarse variety of "redstone" facies of Krynine, 1950), in layers 2 to 20 ft thick. These strata are repeated by faults dipping about 30° W. Subtracting for these repetitions and including a covered interval next to the fault lying west of the exposures, a tape-and-compass traverse along the side of the road suggests a thickness of 114 ft of strata beneath the volcanic rock.

In the conglomerate layers cobbles and boulders of greenschists, feldspathic quartzites, granitic rocks, and gneisses are abundant. The dominant clasts, feldspathic quartzites, probably were derived from the Plainfield Formation. Many of the platy greenschist clasts are imbricated with their long axes steeply inclined in the downdip direction. This suggests stream flow in the updip direction, directly away from the basin-marginal fault.

The abundance of schist clasts is emphasized because this abundance contrasts with the observations of Krynine (1950) and of Fritts (1963) that in the New Haven Arkose N of New Haven, schist clasts become notably less abundant upward in the succession.

The basal part of the volcanic rock capping the knoll at the E end of Face C is a breccia with mineral-filled cavities. Breccia with mineral-lined cavities occurs at the base of the pillowed- and brecciated member of the Talcott Formation, the upper part of which forms Face A.

As I see it, therefore, the rocks in the three faces may be summarized as follows:

Face A:
Formations: Talcott and (?) New Haven.
Stratigraphic position: Pillowed- and brecciated member (main part of cut), upper breccia member, Shuttle Meadow Formation, and (?)New Haven Arkose (or one of lower sedimentary members of Talcott).
Distance from border fault: 0.12 mi.
Particle sizes of sedimentary strata: silt, sand, and cobbles.
Attitude of strata: pillowed basalt: N50°E, 10°SE; conglomerate: N85°W, 25°SW.
Structural setting: Saltonstall syncline; upfaulted block along basin-marginal fault.

Face B:

Formation: Talcott.
Stratigraphic position: Lower part of upper breccia member and basal contact with upper sedimentary member.
Distance from border fault: 0.17 mi.
Particle sizes of sedimentary strata: clay, silt, and very fine sand.
Attitude of strata: N75°E, 5° to 10°NW.
Structural setting: Saltonstall syncline; upfaulted block along the basin-marginal fault.

Face C:
Formation: Talcott.
Stratigraphic position: middle sedimentary member (or New Haven Arkose) and pillowed- and brecciated member.
Distance from border fault: 0.05 mi.
Particle size of sedimentary strata: coarse sand to coarse boulders.
Attitude of strata: N60°W, 30° to 35°NE.
Structural setting: Saltonstall syncline; upfaulted block along basin-marginal fault.

If these assignments are correct, then each face is separated from the other faces by one or more faults. Two sets of faults are inferred, the principal one striking N25°W and a subordinate one striking N60°E. These two sets are in addition to the main fault lying west of the belt of volcanic rock, which strikes N10°E. The oldest strata are exposed in Face C and at the eastern end of Face A; the youngest strata (Shuttle Meadow Formation) are present near the E end of Face A.

STOP 9 - Proterozoic Stony Creek Granite at Stony Creek, remobilization rather than classical intrusion? [UTM Coordinates: ~688.25E / 4570.82N, Branford quadrangle.]

You're on your own.

STOP 10 - Lighthouse granite-gneiss, Lighthouse Point Park, New Haven, CT. [UTM Coordinates of BM @ +31': 675.75E / 4568.52, Branford quadrangle.]

You're on your own.

It's time to go home. I hope you enjoyed the trip! Onward with On-The-Rocks, wherever that may lead.

ACKNOWLEDGEMENTS

My field work on the Branford quadrangle was supported by the Connecticut Geological and Natural History Survey, who have probably given up all hope that I will ever submit a finished map and accompanying bulletin. Because of insurance problems with the Academy that forced CM to "walk away" from the loss of liability, this trip started out as a solo venture. My burden was been greatly eased when Charles Merguerian helped by picking up the 15-passenger van in Garden City, Long Island, and driving to the New York Academy to pick up most of the participants and assisted in conducting the trip. This arrangement enabled me and some others to join the trip at the Cross County Shopping Center.

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	(Passive-margin sequence 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.
	190	Continued filling of subsiding Newark basins and mafic igneous
(Triassic)		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). Arc-continent collision.
(Ordovician)		Great overthrusting from ocean toward continent. Taconic deep-water strata thrust above shallow-water strata. Ultramafic rocks (oceanic lithosphere) sliced off and transported 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, part of Manhattan Schist Fm.). Deep-water terrigenous silts form to east. (= Taconic Sequence; protoliths of Hartland Formation, parts of Manhattan Schist Fm.). (Passive-margin sequence I).

PROTEROZOIC

	570	Period of uplift and erosion followed by subsidence of margin.
(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 - Names, abbreviations, descriptions and thicknesses of Upper Triassic to Lower Jurassic strata, southern Connecticut
(Names of formations as in Rodgers, Gates, and Rosenfeld, 1959)

Name	Abbreviation	Description and Thickness (ft)
Portland Formation	Jp	Conglomerates, coarse sandstones and fine-textured, well-bedded maroon-, gray and black strata; top eroded (1,600).
Hampden Formation	Jha	Extrusive basalt; locally two sheets separated by about 40 feet of sedimentary strata (200).
East Berlin Formation	Jeb	Sedimentary strata; sandstones and siltstones away from basin-marginal fault; conglomerates near fault (1,500).
Holyoke Formation	Jho	Extrusive basalt; at least two flow units represented. Three members: basal dolerite, middle dolerite and gabbro, upper basalt (450).
Shuttle Meadow Formation	Jsm	Sedimentary strata; fine sandstones and siltstones away from basin-marginal fault; conglomerates near fault (1,500).
Talcott Formation:	Jt	
Upper breccia member	Jtb	Massive basalt breccia; some framents of crystalline rocks; matrix contains quartz and feldspar up to coarse sand size (200).
Upper sedimentary member	Jsu	Coarse pebbly arkose at base; siltstone and carbonate rocks in upper part (250).
Pillowed and brecciated member	Jpb	Pillowed extrusive basalt in lower of two sheets; breccia in upper sheet (200).
Middle sedimentary member	Jms	Coarse pebbly arkose (60+).
Lower massive member	Jte	Fine-textured extrusive basalt; well-developed columnar joints (100).
Lower sedimentary member	Jsl	Coarse pebbly arkose (40).
Basal member	Jtba	Fine-textured extrusive basalt; locally brecciated and amygdaloidal (150).
New Haven Arkose	Tnh	Coarse- and fine arkose; base not exposed (5,000+).

TOTAL AGGREGATE THICKNESS = (10,650'+)

Table 03 – Proposed new classification of the Pleistocene deposits of New York City and vicinity (Sanders and Merguerian, 1998, Table 2)

Age	Till No.	Ice-flow Direction	Description; remarks
Late Wisconsinan ("Woodfordian"?)	I	NNE to SSW	Gray-brown till in Westchester Co., Staten Is., Brooklyn, & Queens (but not present on rest of Long Island); Hamden Till in CT with terminal moraine lying along the S coast of CT; gray lake sediments at Croton Point Park, Westchester Co.
Mid-Wisconsinan (?)			Paleosol on Till II, SW Staten Island.
Early Wisconsinan(?)	II	NW to SE	Harbor Hill Terminal Moraine and associated outwash (Bellmore Fm. in Jones Beach subsurface); Lake Chamberlain Till in southern CT.
Sangamonian(?)			Wantagh Fm. (in Jones Beach subsurface).
	IIIA	NW to SE	Ronkonkoma Terminal Moraine and associated outwash (Merrick Fm. in Jones Beach subsurface).
Illinoian(?)	IIIB		Manhasset Fm. of Fuller (with middle Montauk Till Member; in lower member, coarse delta foresets (including debris flows) deposited in Proglacial Lake Long Island dammed in on S by pre-Ronkonkoma terminal moraine.
	IIIC		
Yarmouthian			Jacob Sand, Gardiners Clay.
Kansan(?)	IV	NNE to SSW	Gray till with decayed stones at Teller's Point (Croton Point Park, Westchester Co.); gray till with green metavolcanic stones, Target Rock, LI.
Aftonian(?)			No deposits; deep chemical decay of Till V.
Nebraskan (?)	V	NW to SE	Reddish-brown decayed-stone till and -outwash at AKR Co., Staten Island, and at Garvies Point, Long Island; Jameco Gravel fills subsurface valley in SW Queens.
			Pre-glacial (?) Mannetto Gravel fills subsurface valleys.

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