DUKE GEOLOGICAL LABORATORY

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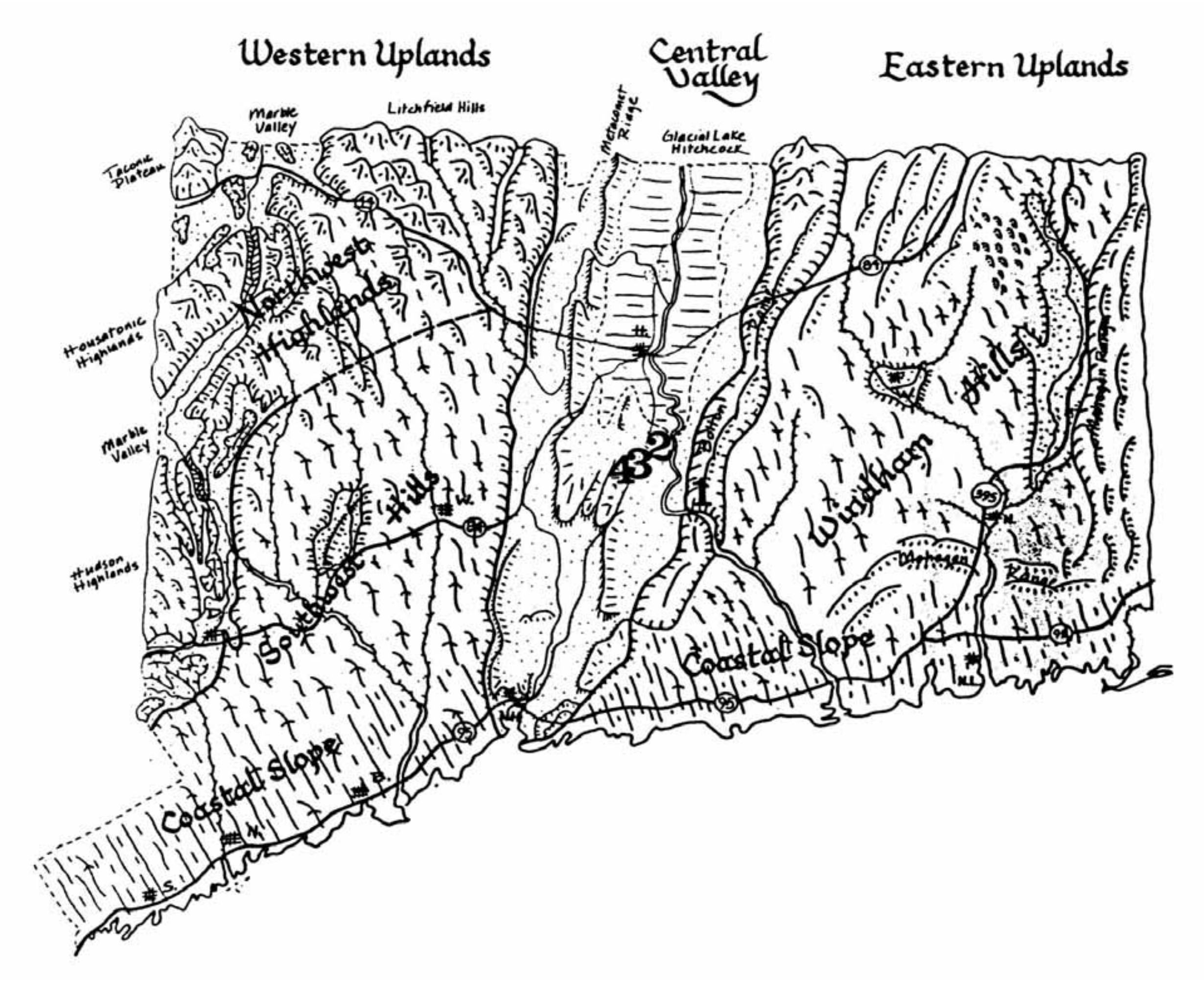
TRIPS ON THE ROCKS

Guide 15: Connecticut Mines and Dinosaurs

Trip 18: 16 June 1991; Trip 31: 18 June 1994



Field Trip Notes by:

Charles Merguerian and John E. Sanders

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Guide 15: Connecticut Mines and Dinosaurs

Trip 18: 16 June 1991
Trip 31: 18 June 1994

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

INTRODUCTION

Trip 31 to the wilds of central Connecticut is intended to introduce the participants to the geology of the strata that filled the Hartford Basin and to visit Dinosaur State Park and one of the region's former strategic-mineral prospects. We will examine and collect minerals and rocks from a site in the crystalline highlands of eastern Connecticut and in the adjacent Hartford Basin (Figure 1, on cover). In addition, we will discuss the regional geologic relationships of the field-trip route placing particular emphasis on the geology of the crystalline uplands of western Connecticut, the Mesozoic development of the Hartford Basin and the mid-Jurassic deformation of the basin-filling strata, and the effects of Pleistocene glaciers in sculpting the landscape.

We plan to drive eastward from the Academy across to the FDR Drive and northward to the Major Deegan Expressway. From there, we will travel east on the Cross Bronx Expressway (across Cameron's Line, a major structural-stratigraphic dislocation within the Manhattan Prong) and northeastward on the New England Thruway (I-95) into the crystalline terrane of western Connecticut. We will then switch to I-91 Northbound and travel along the strike valley formed by the eastward-dipping strata composing the fill of the Hartford Basin. After a brief rest stop on I-91, we will loop back toward Middletown, cross the Connecticut River and the basin-margin fault and enter Portland, Connecticut on our way to the Case beryl prospects (Stop 1).

From this mineral site, we will then backtrack westward across the basin-marginal fault and the Connecticut River for a lunch stop and a bit of messing about making plaster casts at Dinosaur State Park, Rocky Hill (Stop 2). From Rocky Hill, we will travel southward on Route I-91 to view spectacular exposures of volcanic- and sedimentary rocks on Connecticut Route 9 (Stop 3) and Route 372 (Stop 4) before returning to the concrete- and glass labyrinth surrounding the Academy.

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) and Table 2, which summarizes the major local geologic units we will encounter on our trip in terms of superimposed layers designated by Roman numerals from I (oldest) to VII (youngest).

GEOLOGIC BACKGROUND

Under this heading, we provide a primer on geologic structure and sedimentary structures, discuss the bedrock units, the geology of Connecticut and Cameron's Line, glacial deposits, and the drainage history of our field-trip route.

GEOLOGIC STRUCTURE - A PRIMER

Geologists use terminology to confuse the layman and to enable them to amass a huge library of terms that are undeniably useless in most social situations. Our On-The-Rocks trips are an exception. Luckily, and we will not try to bury you in a mountain (how about a deeply eroded mountain range?) of terms to help you understand the major types of structures and geologic features that you will read- and hear about today. But, if you are to understand what we are talking about, you need to know some important definitions. In the following section, we describe folds, faults, surfaces of unconformity, sedimentary structures, and structures in sedimentary- vs. metamorphic rocks.

We begin with some concepts and definitions based on the engineering discipline known as strength of materials. Given today's sophisticated laboratory apparatus, it is possible to subject rocks to temperatures- and pressures comparable to those found deep inside the Earth.

Imagine taking a cylinder of rock out of the Earth and torturing it in a tri-axial compression machine to see what happens. Some geologists get a big charge out of this and tell us (the field geologists) that they really understand how rocks behave under stress. [CM thinks they need to perform these experiments over a longer time frame than a few generations of siblings will allow and thus relies more on field observation and inference than from rock-squeezing data to gain a feel for the complex nature of how rocks are deformed in nature.]

Despite the limitations of the experimental work, measurements in the laboratory on specimens being deformed provide some fundamental definitions. One key definition is the elastic limit, which is the point at which a test specimen no longer returns to its initial shape after the load has been released. Below the elastic limit, the change of shape and/or volume (which is known as strain) is proportional to the stress inside the specimen. Above the elastic limit, the specimen acquires some permanent strain. In other words, the specimen has "failed" internally. Irrecoverable strain manifests itself in the distorsion of crystal lattices, grain-boundary adjustments between minerals composing the rock, and minute motions along cleavage- or twin planes.

When differential force is applied slowly (or, according to CM, over long periods of time), rocks fail by flowing. This condition is defined as behaving in a ductile fashion (toothpaste being squeezed out of a tube is an example of ductile behavior). Folds are the result of such behavior. If the force is applied under low confining pressure or is applied rapidly (high strain rates), rocks do not flow, but fracture. This kind of failure is referred to as rocks behaving in a brittle fashion (as in peanut brittle). The result is faults or joints. Once a brittle failure (fracture) has begun, it will propagate, produce offset, and form a fault surface.

In some cases, during deformation, rocks not only undergo simple strain, but also recrystallize. New metamorphic minerals form and newly formed metamorphic minerals acquire a parallel arrangement. More on metamorphic textures later. From the laboratory studies of rock deformation, a few simple relationships are generally agreed upon regarding brittle- and ductile faulting and these are discussed below.

When subjected to differential forces, under high confining pressures and elevated temperatures, rocks (like humans) begin to behave foolishly, squirming in many directions and upsetting the original orientation of primary- or secondary planar- and linear features within them. Geologists try to sort out the effects of deformation by working out the order in which these surfaces or linear features formed using a relative nomenclature based on four letters of the alphabet: D, F, S, and M. Episodes of deformation are abbreviated by (Dn), of folding by (Fn), of the origin of surfaces (such as bedding or foliation) by (Sn), and of metamorphism by (Mn), where n is a whole number starting with 1 (or in some cases, with zero). Bedding is commonly designated as S_0 (or surface number zero) as it is commonly overprinted by S_1 (the first foliation). To use this relative nomenclature to describe the structural history of an area, for example, one might write: "During the second deformation (D_2), F_2 folds formed; under progressive M_1 metamorphic conditions, an axial-planar S_2 foliation developed."

In dealing with the geologic structures in sedimentary rocks, the first surface one tries to identify positively is bedding or stratification. The boundaries of strata mark original sub-horizontal surfaces imparted to sediments in the earliest stage of the formation of sedimentary rock. Imagine how such strata, buried by the weight of overlying strata and laterally compressed by the advance of lithospheric plates, are subjected to the differential force necessary for folds to form. Contrary to older ideas, we now realize that vertical burial cannot cause regional folds (although small-scale slumping and stratal disharmony are possible). Rather, tangential force must be applied to provide the driving force to create folds and faults.

It's time to turn to some geometric aspects of the features formed as a result of deformation of rocks in the Earth. We start with folds.

Folds

If layers are folded into convex-upward forms we call them anticlines. Convex-downward fold forms are called synclines. In Figure 2, note the geometric relationship of anticlines and synclines. Axial planes (or axial surfaces) physically divide folds in half. Note that in Figure 15, the fold is deformed about a vertical axial surface and is cylindrical about a linear fold axis which lies within the axial surface. The locus of points connected through the domain of maximum curvature of the bedding (or any other folded surface of the fold) is known as the hinge line (which is parallel to the fold axis). This is geometry folks; we have to keep it simple so geologists can understand it.

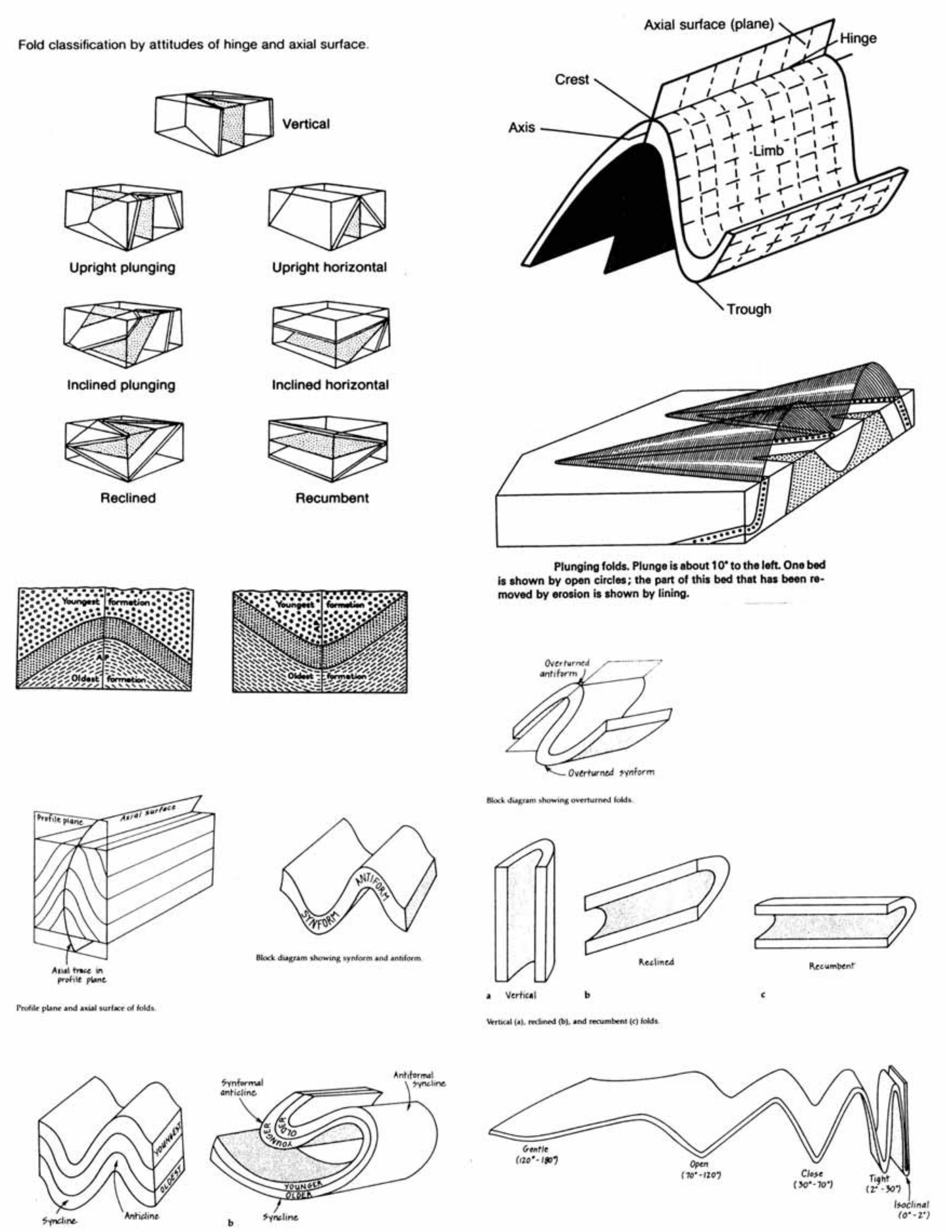


Figure 2 - Composite diagram from introductory texts showing various fold styles and nomenclature as discussed in the text.

In eroded anticlines, strata forming the limbs of the fold dip away from the central hinge area or core (axis) of the structure. In synclines, the layers forming the limbs dip toward the hinge area. Given these arrangements, we expect that in the arches of eroded anticlines, older stratigraphic layers will peek through whereas in the eroded troughs of synclines, younger strata will be preserved.

In metamorphic terranes, field geologists are not always sure of the correct age relationships of the metamorphosed strata. Therefore, it is helpful to make use of the general terms antiform and synform that describe the folds by whether they are convex upward (antiform) or concave upward (synform) but do not imply anything about the relative ages of the strata within them.

Realize that in the upright folds shown in Figure 2, axial surfaces are vertical and fold axes, horizontal. Keep in mind that folding under metamorphic conditions commonly produces a penetrative mineral fabric with neocrystallized minerals (typically micas and amphiboles) aligned parallel to the axial surfaces of folds. Such metamorphic fabrics are called foliation, if primary, and schistosity, if secondary. Minerals can also align in a linear fashion producing a metamorphic lineation. Such features can be useful in interpreting a unique direction of tectonic transport or flow direction. Because folds in metamorphic rocks are commonly isoclinal (high amplitude-to- wavelength aspect ratio) with limbs generally parallel to axial surfaces, a penetrative foliation produced during regional dynamothermal metamorphism will generally parallel the re-oriented remnants of stratification (except of course in the hinge areas of folds). Thus, in highly deformed terranes, a composite foliation + remnant compositional layering is commonly observed in the field. Departures from this common norm are important to identify as they tend to mark regional fold-hinge areas.

Folds could care less about the orientation of their axes or axial surfaces and you can certainly imagine that axial surfaces can be tilted, to form inclined or overturned folds. Or the axial surfaces may be sub-horizontal, in which case the term recumbent folds is used. In both overturned folds and recumbent folds, the fold axes may remain subhorizontal. (See Figure 2.) It is also possible for an axial surface to be vertical but for the orientation of the fold axis to range from horizontal to some angle other than 0° (thus to acquire a plunge and to produce a plunging fold). Possible configurations include plunging anticlines (or -antiforms) or plunging synclines (or -synforms). Vertical folds (plunging 90°) are also known; in them, the terms anticline and syncline are not meaningful. In reclined folds, quite common in ductile fault zones (See below.), the fold axes plunge directly down the dip of the axial surface.

In complexly deformed mountain ranges, most folds show the effects of more than one superposed episode of deformation. As a result of multiple episodes of deformation, the ultimate configuration of folds can be quite complex (i. e., plunging folds with inclined axial surfaces and overturned limbs).

We need to mention one other point about the alphabet soup of structural geology. Seen in cross section, folds fall into one of three groups, the S's, M's, and the Z's. Usually only one variety of small folds will be found on a given limb of a larger fold. Therefore, if one notices a change in the pattern from S folds to Z folds (or vice versa), one should be on the lookout for a fold axis. The hinge area is dominated by M-folds (no sense of asymmetry).

One final note on folding -- it is generally agreed, in geologically simple areas, that axial surfaces form perpendicular to the main forces that produced the fold. Therefore, the orientation of the folds give some hint as to the direction of application of the active forces (often a regional indicator of relative plate convergence). In complex regions, the final regional orientation of the structures is a composite result of many protracted pulses of deformation, each with its unique geometric attributes. In these instances, simple analysis is often not possible. Rather, a range of possible explanations for a given structural event is commonly presented.

Faults

A fault is defined as a fracture along which the opposite sides have been displaced. The surface of displacement is known as the fault plane (or fault surface). The enormous forces released during earthquakes produce elongate gouges within the fault surface (called slickensides) that may possess asymmetric linear ridges that enable one to determine the relative motion between the moving sides (Figure 3). The block situated below the fault plane is called the footwall block and the block situated above the fault plane, the hanging-wall block. Extensional force causes the hanging-wall block to slide down the fault plane producing a normal fault. [See Figure 3 (a).] Compressive forces drive the hanging-wall block up the fault plane to make a reverse fault. A reverse fault with a low angle (<30°) is called a thrust fault. [See Figure 3 (b).] In all of these cases, the slickensides on the fault will be oriented more or less down the dip of the fault plane and the relationship between the tiny "risers" that are perpendicular to the striae make it possible to determine the relative sense of motion along the fault. Fault motion up- or down the dip (as in normal faults, reverse faults, or thrusts faults) is named dip-slip motion.

Rather than simply extending or compressing a rock, imagine that the block of rock is sheared along its sides (i. e., that is, one attempts to rotate the block about a vertical axis but does not allow the block to rotate). This situation is referred to as a shearing couple and could generate a strike-slip fault. [See Figure 3 (c).] On a strike-slip-fault plane, slickensides are oriented subhorizontally and again may provide information as to which direction the blocks athwart the fault surface moved.

Two basic kinds of shearing couples and/or strike-slip motion are possible: left lateral and right lateral. These are defined as follows. Imagine yourself standing on one of the fault blocks and looking across the fault plane to the other block. If the block across the fault from you appears to have moved to the left, the fault is left lateral [illustrated in Figure 3 (c)]. If the block across the fault appears to have moved to the right, the motion is right lateral. Convince yourself that no matter which block you can choose to observe the fault from, you will get the same result! Naturally, complex faults show movements that can show components of dip-slip- and strike-slip motion, rotation about axes perpendicular to the fault plane, or reactivation in a number of contrasting directions or variety. This, however, is no fault of ours.

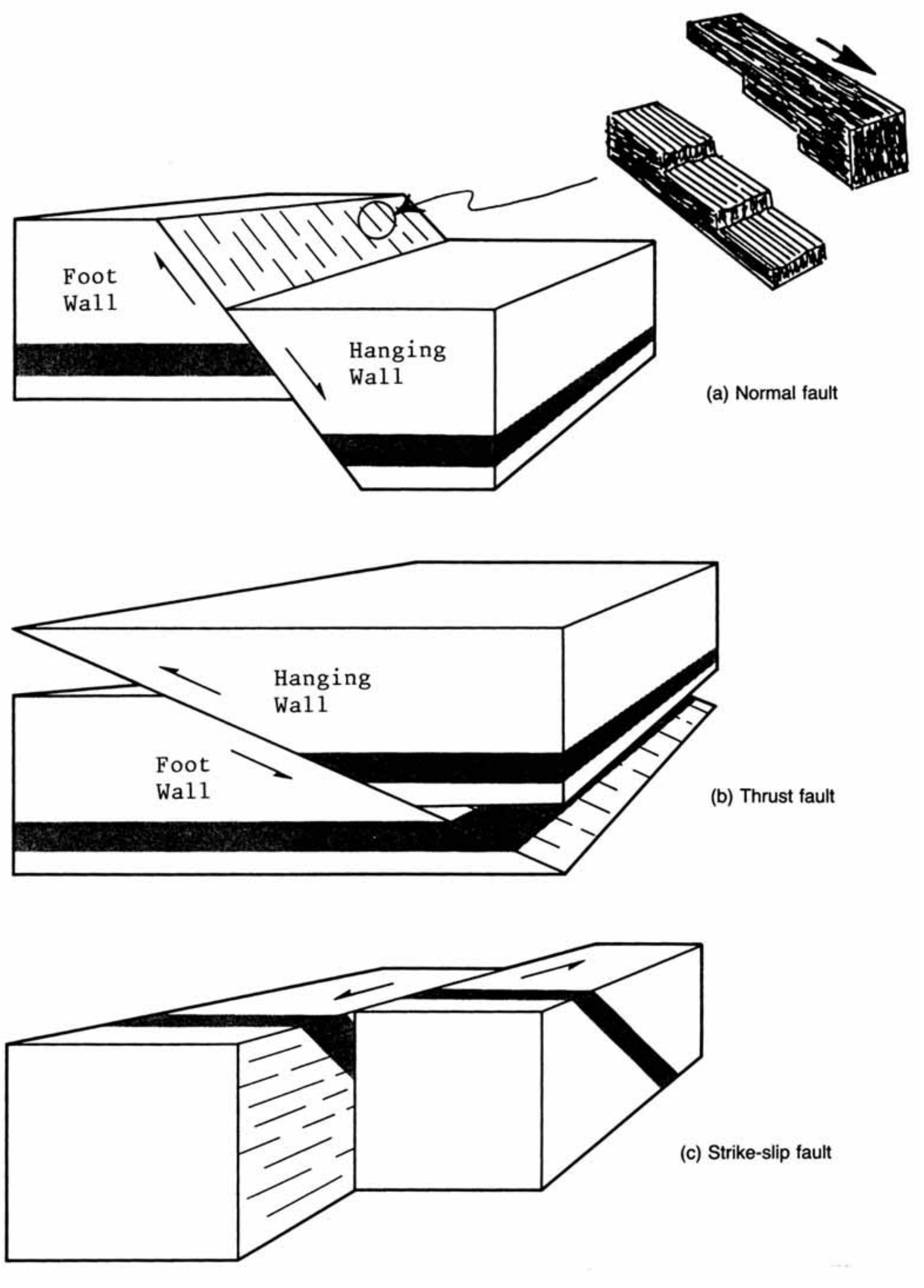


Figure 3 - The three main types of faults shown in schematic blocks. Along a normal fault (a) the hanging-wall block has moved relatively downward. On a thrust fault (or reverse fault) (b) the hanging-wall block has moved relatively upward. Along a strike-slip fault (c), the vertical reference layer (black) has been offset by horizontal movement (left-lateral offset shown here). Inset (d) shows segments of two blocks along a slickensided surface show how the jagged "risers" of the stairsteps (formed as pull-apart tension fractures) can be used to infer sense of relative motion. [(a), (b), (c), Composite diagram from introductory texts; (d), J. E. Sanders, 1981, fig. 16.11 (b), p. 397.]

Tensional- or compressional faulting resulting from brittle deformation, at crustal levels above 10 to 15 km, is accompanied by seismicicity and the development of highly crushed and granulated rocks called fault breccias and cataclasites (including fault gouge, fault breccia, and others). Starting at roughly 10 to 15 km and continuing downward, rocks under stress behave aseismically and relieve strain by recrystallizing during flow. These unique metamorphic conditions prompt the development of highly strained (ribboned) quartz, feldspar porphyroclasts (augen), and frayed micas, among other changes, and results in highly laminated rocks called mylonites. The identification of such ductile fault rocks in complexly deformed terranes can be accomplished only by detailed mapping of metamorphic lithologies and establishing their geometric relationship to suspected mylonite zones. Unfortunately, continued deformation under load often causes early formed mylonites to recrystallize and thus to produce annealed mylonitic textures (Merguerian, 1988), which can easily be "missed" in the field without careful microscopic analysis. Cameron's Line, a recrystallized ductile shear zone showing post-tectonic brittle reactivation, is an original ductile fault zone (mylonite) having a complex geologic history.

Surfaces of Unconformity

Surfaces of unconformity mark temporal gaps in the geologic record and commonly result from periods of uplift and erosion. Such uplift and erosion is commonly caused during the terminal phase of regional mountain-building episodes. As correctly interpreted by James Hutton at the now-famous surface of unconformity exposed in the cliff face of the River Jed, such surfaces represent mysterious intervals of geologic time where we really do not have a clue as to what went on! By looking elsewhere, the effects of a surface of unconformity of regional extent can be recognized and piecemeal explanations of evidence for filling in the missing interval may be found.

Following the proposal made in 1963 by L. L. Sloss, surfaces of unconformity of regional extent within a craton are used as boundaries to define Stratigraphic Sequences.

Sedimentary Structures

During deposition in a variety of environments, primary- and secondary sedimentary structures can develop above-, below-, and within strata. During normal deposition, or settling from a fluid in a rainfall of particles, massive, essentially poorly stratified successions may result. The presence of strata implies a change in deposition and as a result most geologists appreciate the significance of layering in sedimentary rocks as marking CHANGE in big letters, be it a change in parent area of the sediment, particle size, or style of deposition. Thus, bedding can best be viewed as marking the presence of mini-surfaces of unconformity (diastems). During high-energy transport of particles, features such as cross beds, hummocky strata, asymmetric current ripple marks, or graded beds result. Cross- and hummocky bedding, and asymmetric current ripple marks are deposited by moving currents and help us unravel the paleocurrent directions during their formation. Graded beds result from a kind of a "lump-sum distribution" of a wide range of particles all at once (usually in a gravity-induced turbidity flow).

Thus, graded beds show larger particle sizes at the base of a particular layer "grading" upward into finer particles.

Secondary sedimentary features are developed on already deposited strata and include mud (or desiccation) cracks, rain- drop impressions, sole marks, load-flow structures, flame structures, and rip-up clasts. The last three categorize effects produced by a moving body of sediment on strata already in place below. A composite diagram illustrating these common structures is reproduced in Figure 4.

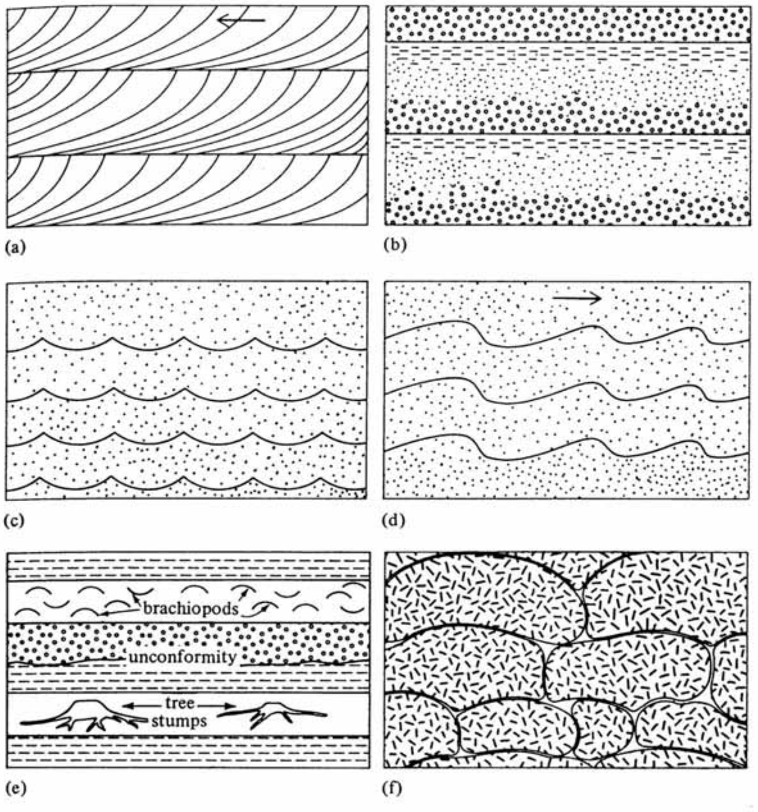


Figure 4 - Diagrammatic sketches of primary sedimentary structures (a through e) and cross sections of pillows (f) used in determining topping (younging) directions in rocks.

Appropriate to today's trip, another class of sedimentary structure is produced by the feet of wandering organisms (dinosaurs in the present context). Impressions of footprints can develop in unconsolidated mud, silt, or organic layers in very shallow water or exposed in mud flats (Figure 5). The weight of the organism would create a depression in the top surface of the underlying stratum. Subsequently, long after the organism is gone, the impression may be filled in by sandy sediment. Useful in determining topping direction (as described below), the footprints of organisms are studied by podiatric paleontologists to determine the marching direction of the organism and can also elucidate the type of march (run or walk), allow conjecture as to hip- and leg- bone movement mechanisms, and help determine the center of gravity of the critters. Such studies are of great importance in recontructing models of the skeletal- and body structure of dinosaurs and other organisms.

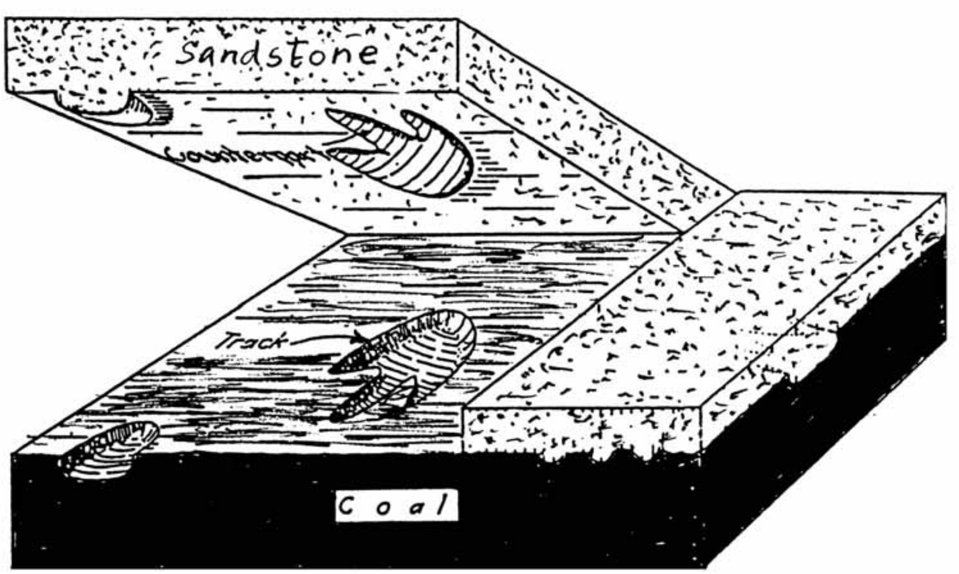


Figure 5 - Sketch of several dinosaur footprints made in swampy Cretaceous material in what is now Wyoming that became a coal (black, below) that were preserved as counterparts on the base of the overlying layer of terrigenous sediment (stippled) that covered the footprints. The complete footprint shown 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.)

Together, these primary- and secondary sedimentary structures help the soft-rock structural geologist unravel the oft-asked field questions - namely.... Which way is up? and Which way to the package store? The direction of younging of the strata seems obvious in horizontal- or gently tilted strata using Steno's principle of superposition. But steeply tilted-, vertical-, or overturned beds can be confidently unravelled and interpreted structurally only after the true topping (stratigraphic younging) direction has been determined. As we may be able to demonstrate on this field trip, simple observations allow the card-carrying geologist to know "Which way is up" at all times.

Structures in Sedimentary- vs. Metamorphic Rocks

For hard-rock geologists working in metamorphic terranes, simple sedimentary observations will not allow the card-carrying geologist to know "Which way is up" at all. Rather, because of intense transposition and flow during ductile deformation, stratification, fossils for age dating, tops and current-direction indicators are largely useless except to identify their hosts as sedimentary protoliths. Thus, according to CM, "at the outcrop scale, metamorphism can best be viewed as the great homogenizer." Commonly during metamorphism, the increase in temperature and -pressure and presence of chemically active fluids severely alter the mineral compositions and textures of pre-existing rocks. As a result, in many instances, typical soft-rock stratigraphic- and sedimentologic analysis of metamorphic rocks is not possible.

Tectonostratigraphic Units

In metamorphic terranes, tectonostratigraphic units can best be described as large-scale tracts of land underlain by bedrock with similar age range, paleoenvironment of protolith, and structure. Such terranes are generally bounded by ductile fault zones (mylonites), surfaces of unconformity, or brittle faults. Unravelling the collisional plate-tectonic history of mountain belts is greatly facilitated by identifying former cratonic (ancient crustal), continental-margin, continental-slope-, and rise, deep-oceanic, and volcanic-island tectonostratigraphic units. The major distinction in unravelling complexly deformed mountain belts is to identify former shallow-water shelf deposits (originally deposited on continental crust) and to separate them from deep-water oceanic deposits (originally deposited on oceanic crust). We use the terms miogeosynclinal and eugeosynclinal, respectively, to designated the products of these contrasting depositional realms.

BEDROCK UNITS

Layers I and II: Crystalline Complex of Paleozoic and older rocks

As we begin our journey from the New York Academy of Sciences, a few thoughts about the rocks beneath our feet. The crystalline bedrock exposed in New York City marks the southern terminus of an important sequence of metamorphosed Precambrian to Lower Paleozoic rocks of the Manhattan Prong (Figures 6 and 7) which widens northward into the New England Upland physiographic province of the Appalachian mountain belt. Originally, the New York City strata were, in part, deposited on a complexly deformed sequence of layered feldspathic- and massive granitoid gneiss, amphibolite, and calc-silicate rocks of complicated units known as the Fordham and Yonkers Gneisses (Layer I). As such, the complexly deformed, Proterozoic Y and Z basement sequence (Layer I) represents the ancient continental crust of proto-North America that became a trailing edge, passive continental margin throughout the early Paleozoic Era. Interestingly, the current geologic setting of the continental shelf of eastern North America, with deformed Paleozoic- and older basement covered by Mesozoic- and younger sediments, is analogous to the past (except for differences in age, paleolatitude, geothermal regime, and paleotectonics).

The Cambrian- to Ordovician bedrock units in western Connecticut and New York City (Layer II) now form a deeply eroded sequence of highly metamorphosed, folded, and faulted sedimentary- and igneous rocks (Figure 8) which began life roughly 550-450 million years ago as thick accumulations of both shallow- and deep-water sediments adjacent to the Early Paleozoic shores of proto-North America (Figure 9). Layer II can be divided into two sub-layers, IIA and IIB.

The older of these, IIA, represents the ancient passive-margin sequence of the proto-Atlantic (Iapetus) ocean. These rocks can be subdivided into two facies that differ in their original geographic positions with respect to the shoreline and shelf. A nearshore facies [Layer IIA(W)] was deposited in shallow water on submerged continental crust [Layer I] and is now represented by the Cambrian Lowerre Quartzite and Cambro-Ordovician Inwood Marble in New York City and as the Cheshire Quartzite and the Woodville and Stockbridge marbles in western Connecticut and Massachusetts. These strata began life as sandy and limey sediments in an environment not significantly different from the present-day Bahama Banks.

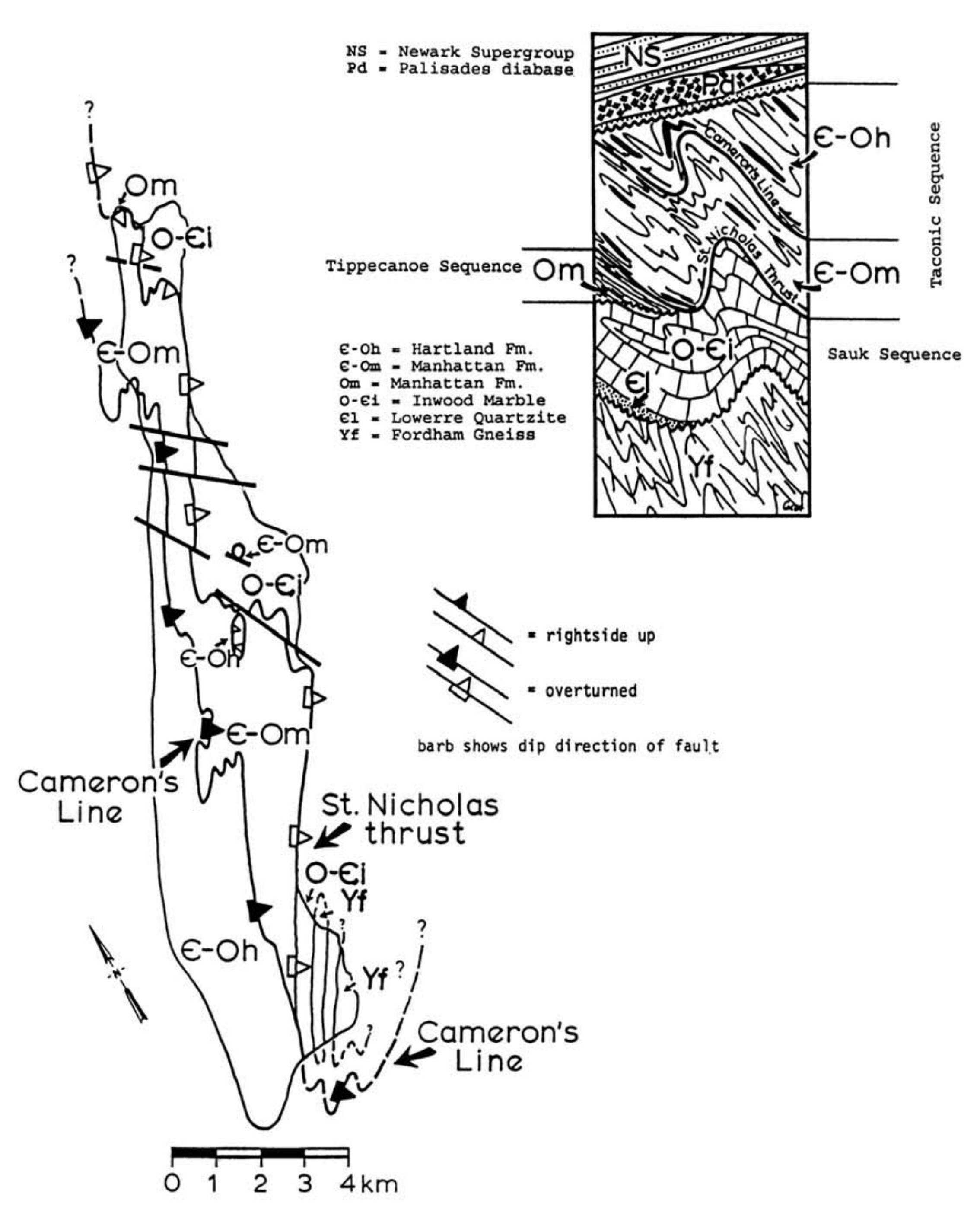


Figure 6 - Geologic map and section of Manhattan. (Mapped by CM, with layer labels, from Table 2, added by JES).

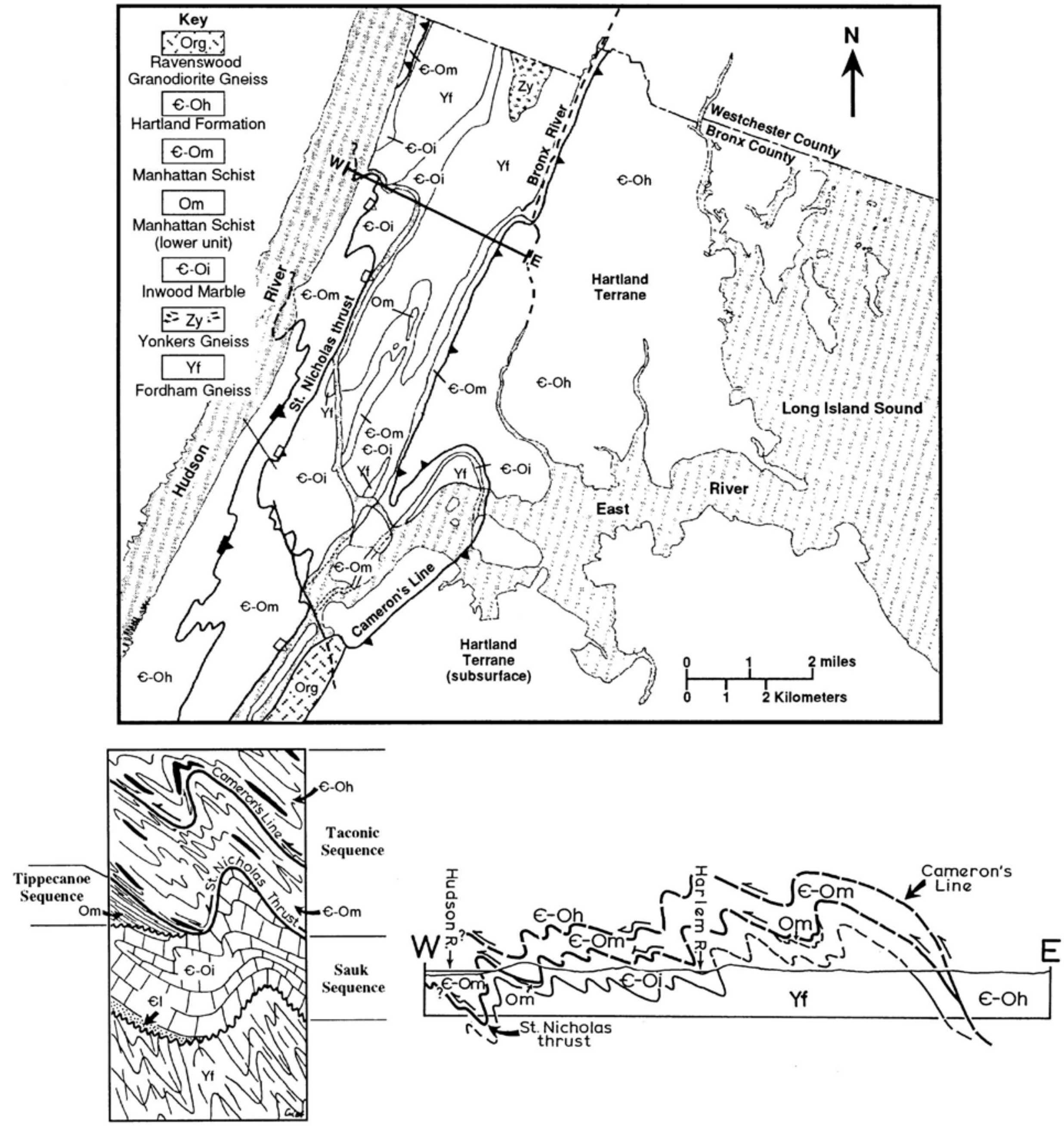


Figure 7 - Geologic map of the southern end of the Manhattan Prong (from Merguerian and Baskerville, 1987).

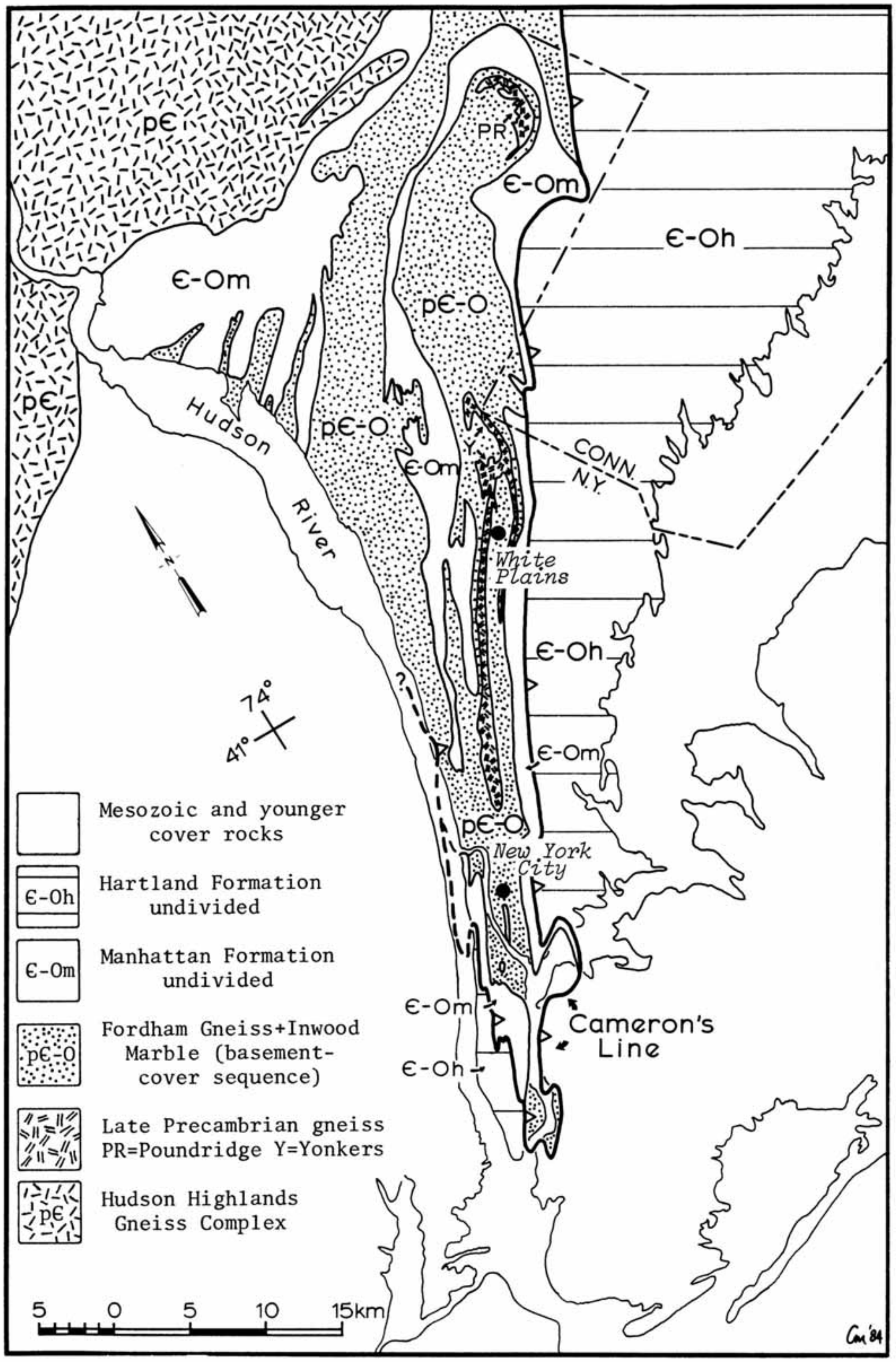


Figure 8 - Simplified geologic map of Manhattan Prong showing the distribution of metamorphic rocks ranging in ages from Proterozoic to Early Paleozoic. Most intrusive rocks have been omitted. (Mose and Merguerian, 1985).

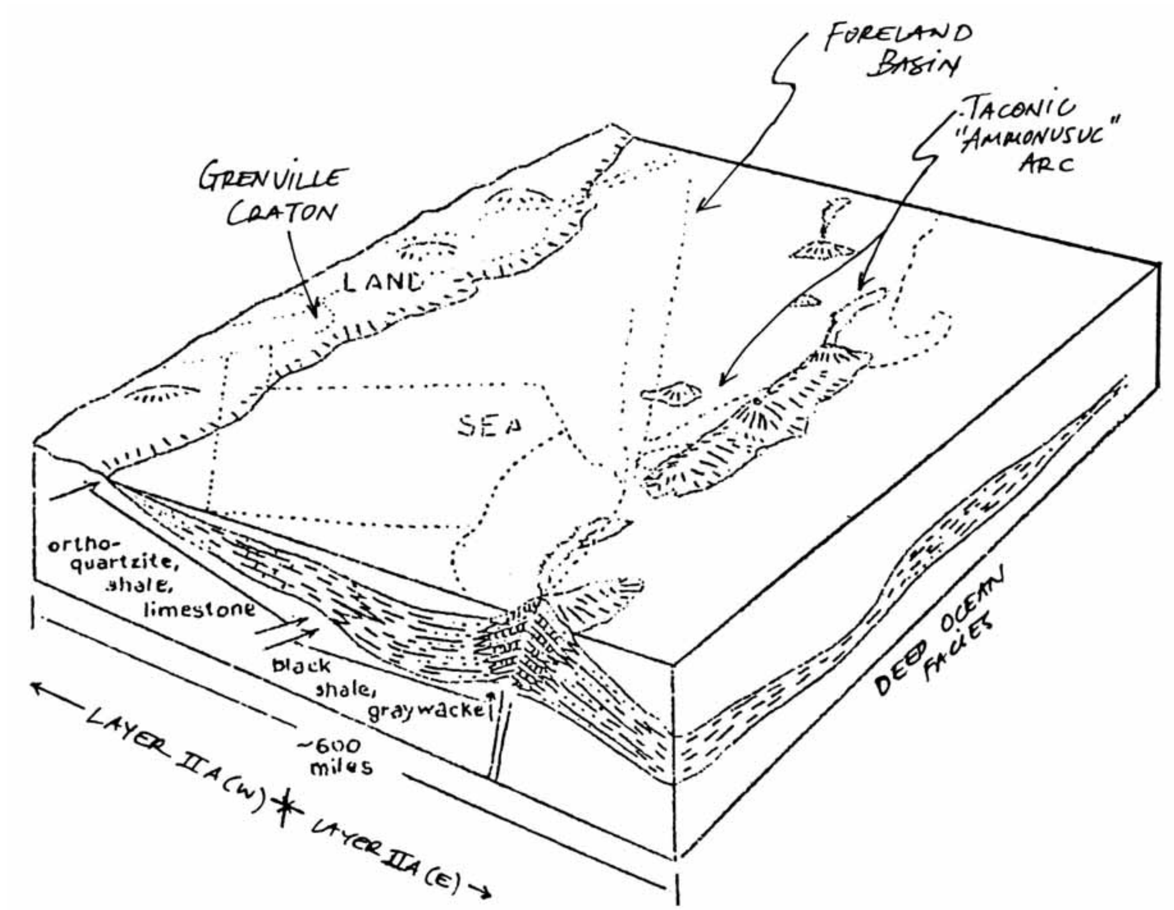


Figure 9 - Paleogeographic block diagram illustrating the passive continental margin of eastern North America during early Paleozoic times.

Farther offshore, fine-grained, terrigenous time-stratigraphic equivalents of the shallow-water strata (shelf sequence) were evidently deposited under deep water on oceanic crust [Layer IIA(E)]. This sequence is also of Cambrian to Ordovician age and is known as the Cambrian to Ordovician Taconic sequence in upstate New York, as units Ꞓ-Ot and Ꞓ-Oh of the Manhattan Schist(s) in Figure 6, and is described below as the Waramaug and Hartland formations, respectively, of western Connecticut.

Layer IIB consists of younger strata that rest, with unconformity, depositionally above the western shallow-water platform [Layer IIA(W)]. In eastern New York State, these rocks are mapped as the Waloomsac and Manhattan formations. In New York City, it is the Manhattan Schist unit Om, which, according to CM, is very local but demonstrably interlayered with the Inwood Marble containing thin layers of calcite marble (Balmville equivalent) at its base at Inwood Hill Park in Manhattan (NYAS On-The-Rocks Trip #16). This field evidence is used to indicate that unit Om of the Manhattan Schist is "in place where found" (the fancy term geologists use for this is autochthonous) and is therefore younger, or the same age, as allochthonous (or "not in place where found" but transported from elsewhere) Manhattan units Ꞓ-Ot and Ꞓ-Oh.

The Geology of Connecticut

As with Caesar's Gaul, all of Connecticut can be divided into three parts (Figure 1, cover) or major geomorphologic belts (or to use a buzz word favored by the in crowd these days, "terranes"). These are: (1) the Western Uplands, (2) the Central Lowlands (labeled "Central Valley" in Fig. 1 on cover), and (3) the Eastern Uplands. In the following discussion, we will emphasize the geology of our trip route only. As such, we will 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.

In 1842, James Gates Percival (15 Sep 1795 - 02 May 1856) published the first state geologic map of Connecticut (Figure 10); Percival's map is so good that modern geologists have to work hard to find changes in his delineation of the rock units. Percival was a melancholy naturalist, a poet, a U. S. Army surgeon, a botanist, and a cunning linguist who collaborated with Webster on the first American dictionary. Clearly a character worthy of further discussion, the interested reader should consult Bell (1985) for more details.

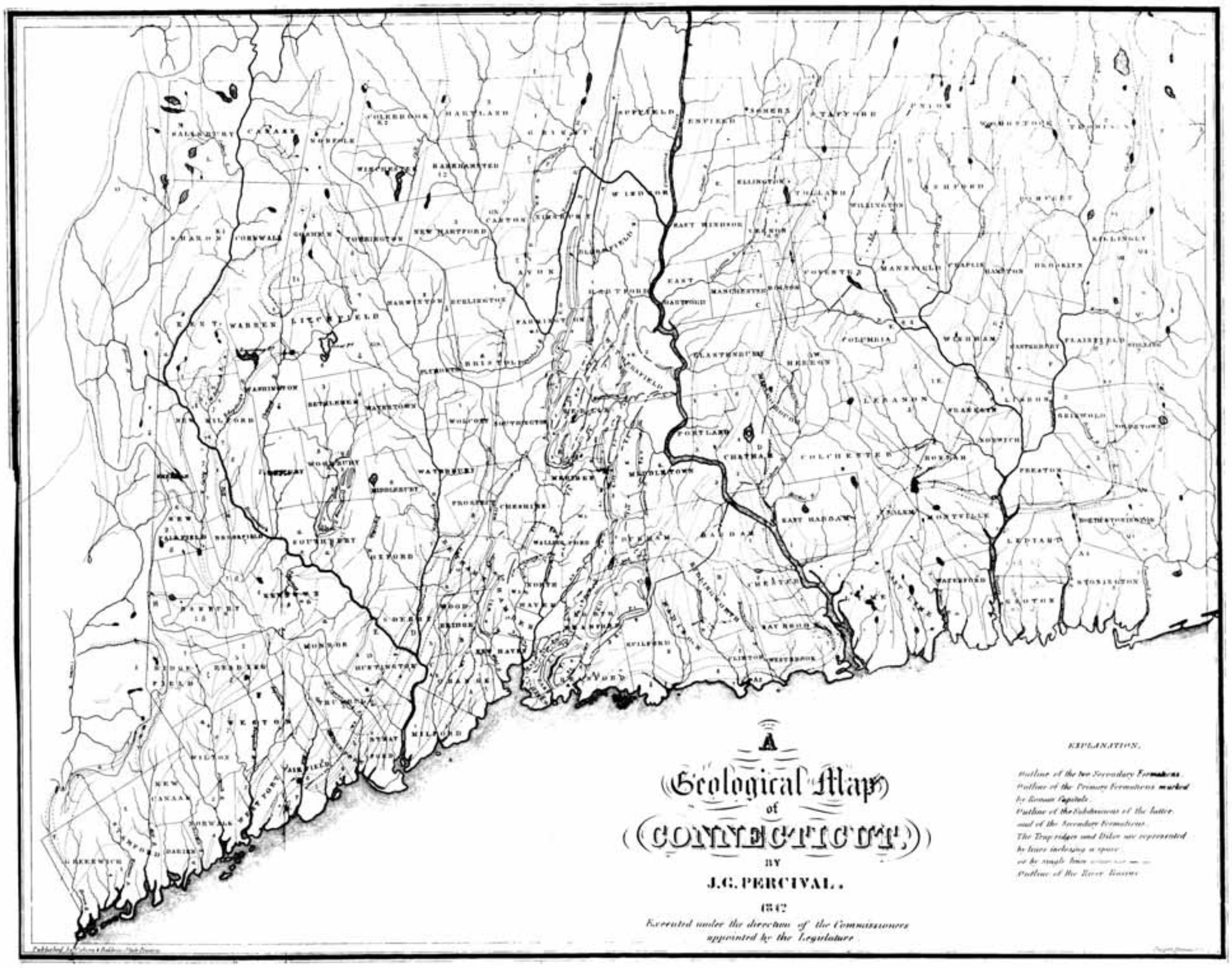


Figure 10 - J. G. Percival's geological map of Connecticut (1842).

In preparing his state map, Percival spent nearly seven years traversing Connecticut along east-west lines at four-mile spacing. He traveled in a one-horse wagon, and by foot. Initially in 1835, Percival was accompanied by C. U. Shepard. By 1837, Shepard had published his comprehensive report on the economic mineral deposits of the state. Later, still not satisfied with the coverage provided by his 4-mile lines, Percival continued his work alone and eventually ran a new set of east-west traverses at 2-mile intervals bisecting his previous 4-mile lines. When he finished, he wrote that he could truthfully say that he had touched every square mile of the entire state of Connecticut. His methods of traverse did not allow him to examine the excellent coastal exposures. Percival's map (1842) is an excellent- and thorough document with a long written report (now a collector's item!) that has proven more correct than modern mapping in certain areas.

The crystalline upland terrane of western Connecticut consists of a diverse assemblage of middle Proterozoic to lower Paleozoic metasedimentary- and metaigneous rocks of the Waramaug and Hartland formations which can be traced from New York City (Layer IIA) northward into the Connecticut Valley-Gasp, synclinorium (a large-scale downfold or "syncline" that affects a broad portion of the Earth's crust) (Figure 11). The autochthonous rocks of Layer IIA(W) crop out in westernmost Connecticut and are continuous with Lower Paleozoic rocks of the Manhattan Prong in southeastern New York. Separated by Cameron's Line, a major ductile shear zone in the New England Appalachians, these two major geological terranes [Layers IIA(W) and IIA(E)] dominate the geologic framework of western Connecticut (Figure 1, cover). On-the-Rocks Trips #6 and ill-fated #13 concentrated on the geology and mineral deposits of the crystalline terrane of Western Uplands of Connecticut.

The Hartland Formation (Cameron, 1951; Gates, 1951, 1952; Merguerian, 1977, 1981, 1983, 1985) consists of aluminous metasedimentary and interlayered metavolcanic rocks. They are bounded on the west by Cameron's Line and to the east, are overlain by metamorphosed rocks of probable Silurian and Devonian age (Hatch and Stanley, 1973). The Hartland Formation (Layer IIA(E)) constitutes the bulk of the crystalline highlands of western Connecticut (Figure 11) and is a highly sheared sequence of metamorphosed eugeosynclinal rocks (meaning formerly deposited in deep water on oceanic crust) now consisting of interlayered muscovite schist, micaceous gneiss and granofels, amphibolite, and minor amounts of calc-silicate rock, serpentinite, and manganiferous- and ferruginous garnet-quartz granofels (coticule).

Occurring to the west of Cameron's Line is an allochthonous sequence of massive gneissic rocks known as the Waramaug Formation (Gates, 1952) of probable Cambrian and ?Ordovician ages (Merguerian, 1983). The Waramaug consists of a heterogeneous assemblage of rusty-, gray-, and locally maroon-weathering gneiss, mica schist, and granofels with subordinate amphibolite gneiss, amphibolite, and calc-silicate rocks (we refer you to On-the-Rocks Trip #13 for specific details). It is correlative to the north with the Cambrian Hoosac Schist and to the south with unit Ꞓ-Ot of New York City. Mapping by Merguerian (1977, 1983a, 1985) in West Torrington, Connecticut; by Jackson (1980), and Jackson and Hall (1982) near Kent, Connecticut; by Alavi (1975) near Bedford, New York; by Hall (1968a, b) in White Plains, New York; and by Merguerian (1983b) and Merguerian and Baskerville (1987) in New York City supports this correlation. The Waramaug sequence is interpreted as a continental slope/rise deposit that was transitional to, and situated between, the depositional sites of Layers IIA(W) and

IIA(E). Thus, on either side of Cameron's Line, strongly disparate sequences of equivalent age occur with lower-plate continental-shelf, -slope, and -rise rocks and upper-plate oceanic rocks juxtaposed along a major zone of mylonite (a ductile shear zone mapped as Cameron's Line).

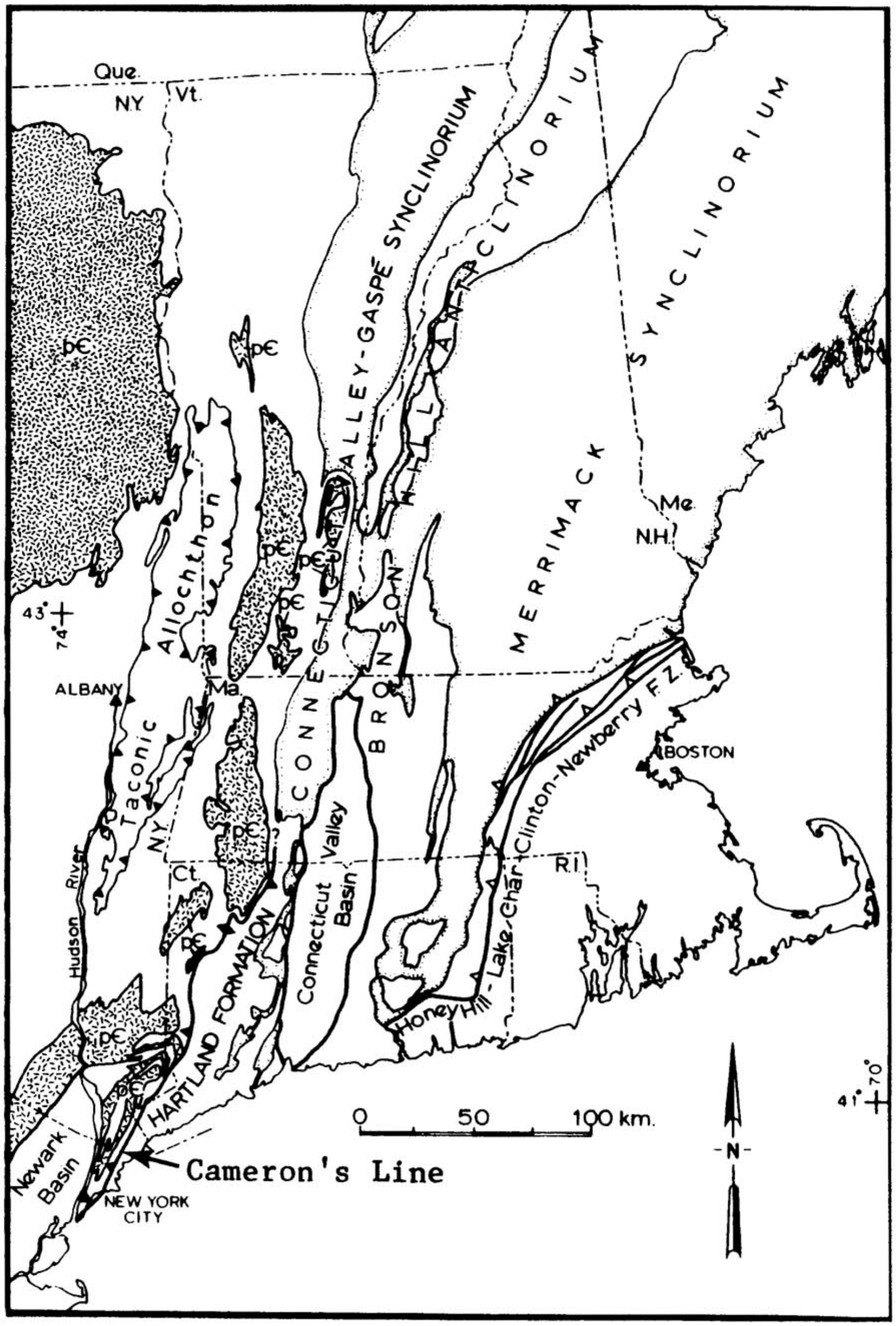


Figure 11 - Tectonic sketch map of southern New England showing the major geotectonic provinces. (Merguerian, 1983a.)

Cameron's Line

According to Eugene Cameron (of Cameron's Line fame) in a confidential personal communication with CM, the geologic relationships of Cameron's Line were first noted by Professor William Agar who shared his insights with E. Cameron. According to EC - "I don't know why they called it Cameron's Line, it should have been called Agar's Line!". In any case, Cameron's Line delimits the easternmost exposures of autochthonous Proterozoic Y and Z gneiss and overlying lower Paleozoic quartzite and marble (shallow-water sedimentary strata [Layer IIA(W)] formed originally on continental crust of proto-North America. Together, Layers I and IIA(W) represent deformed North American craton and overlying shelf deposits.

In western Connecticut, the Hartland Formation or Complex of Merguerian, 1983a) is interpreted as an internally sheared, allochthonous, imbricate thrust package that marks the former site of a deep-seated accretionary complex or subduction zone. Hartland rocks are correlative with metamorphosed eugeosynclinal (deep-water deposition) Cambrian to Ordovician rocks found along strike in New England (Figure 12). Cameron's Line, defined as a zone of intense localized isoclinal folding with sheared-out fold limbs and rootless folds developed under peak Taconian metamorphic conditions, separates the eugeosynclinal Hartland and transitional slope- and rise- rocks of the Waramaug formations in western Connecticut and their correlatives southward in New York City.

Numerous lower Paleozoic calc-alkaline plutons occur in western Connecticut. Near West Torrington, Connecticut, the Hodges mafic-ultramafic complex and the Tyler Lake Granite were sequentially intruded across Cameron's Line (Merguerian, 1977). The plutons are folded along with Cameron's Line in West Torrington, Connecticut. Because of their formerly elongate shapes and because the regional metamorphic fabrics related to the development of Cameron's Line in both the bounding Waramaug and Hartland formations display contact metamorphism, these plutons are interpreted as being late synorogenic. The recognition of significant medial Ordovician plutonism across Cameron's Line (Mose, 1982; Mose and Nagel, 1982; Merguerian and others, 1984; Amenta and Mose, 1985) has established a Taconian or possibly older age for the formation of Cameron's Line and the syntectonic development of regional metamorphic fabrics in western Connecticut (Merguerian, 1985). Judging by metamorphic minerals in the regional fabric, Layers IIA(W) and IIA(E) were juxtaposed at depths of roughly 20 km along Cameron's Line during early Paleozoic times. The force behind such deep-seated deformation presumably resulted from a collision between a volcanic-arc terrane and the passive continental margin of North America (Figure 13). At present, remnants of the volcanic arc terrane are exposed in the Bronson Hill Anticlinorium in New Hampshire and its extension southward on either side of the Central Valley of Connecticut where rocks of the Maltby Lake and Allingtown volcanics crop out. (See Figures 11 and 12.)

In summary, during a series of Paleozoic mountain-building episodes (the Taconic, Acadian, and Appalachian orogenies), the sedimentary protoliths [Layers IIA(W and E) and IIB] of the New England Appalachians were sheared, folded, and metamorphosed during a collision between an exotic volcanic-island chain and the passive continental margin of proto North America. Much of the bedrock in the crystalline uplands of western Connecticut are therefore interpreted as being allochthonous (a fancy term intended to confuse the layman which simply means transported from somewhere else or not deposited where currently found!).

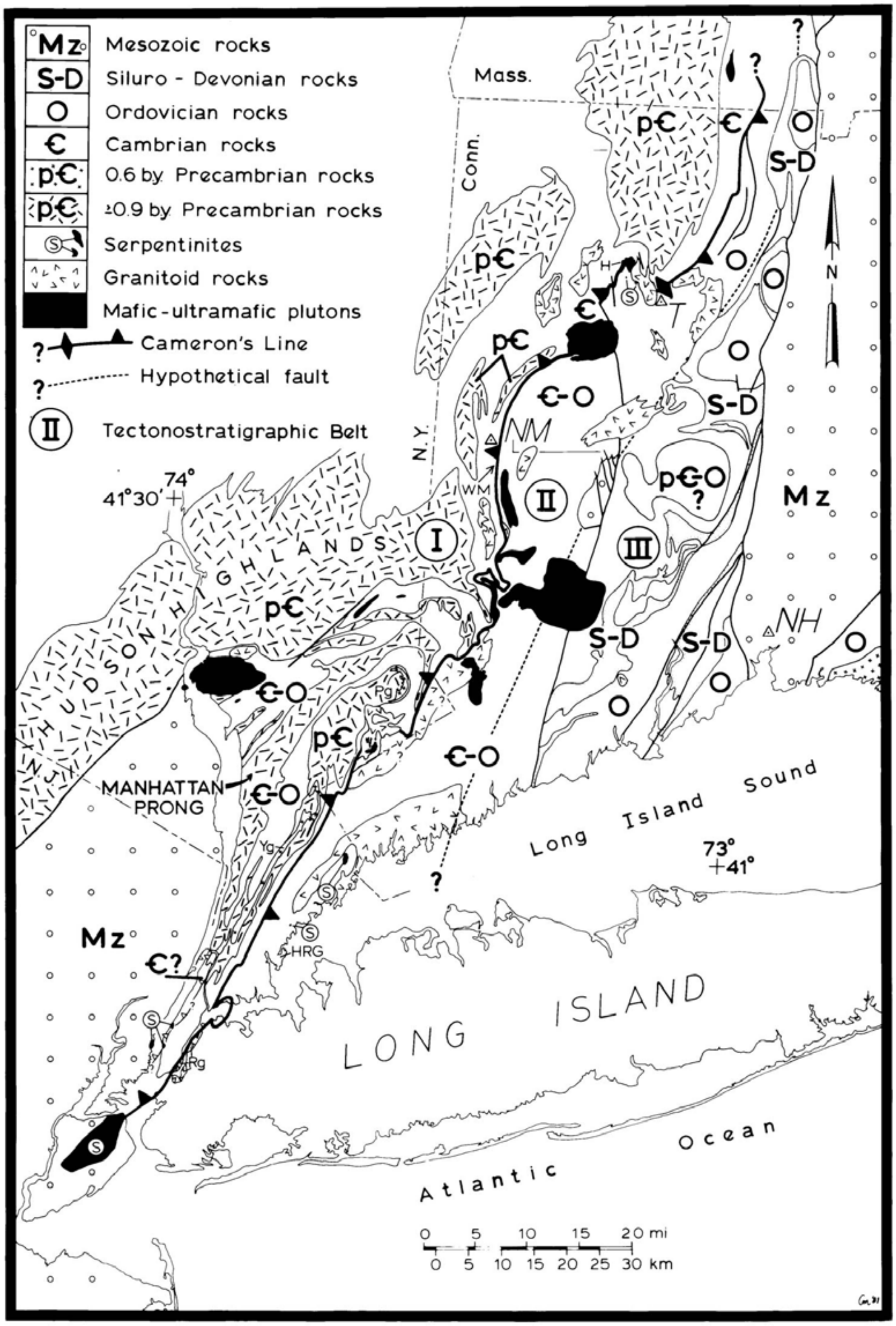
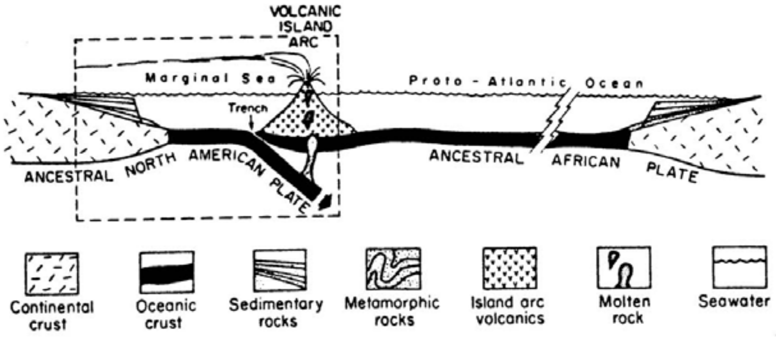
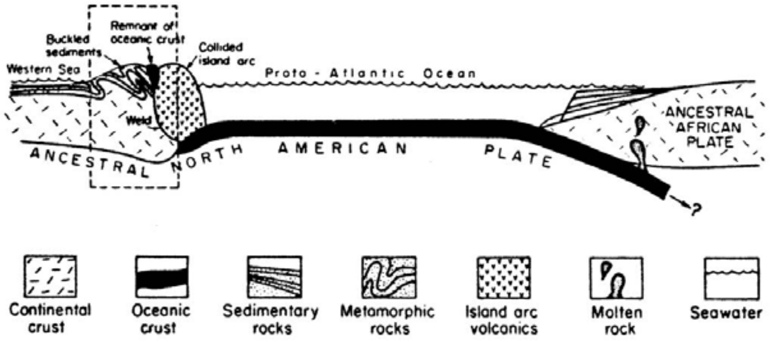


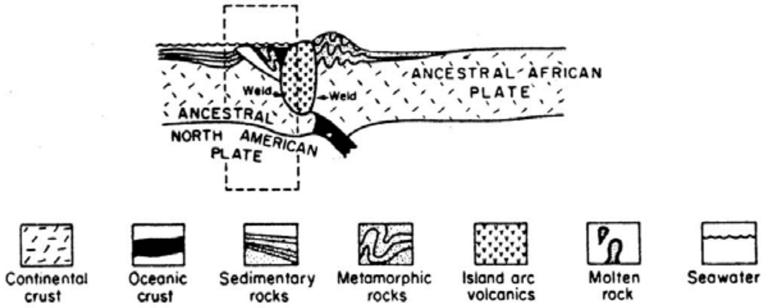
Figure 12 - Geotectonic map of western Connecticut and southeastern New York. (Merguerian, 1983a.)



Reconstructed cross-section for the beginning of Middle Ordovician time, showing North America and an offshore volcanic chain on a collision course. Southeastern New York area of that time is shown by dashed box.



Reconstruction of conditions prevailing after the collision which caused the Taconic Mountain building event. Relict piece of oceanic crust along the weld is the serpentinite of Staten Island. Note approaching ancestral African Plate. Dashed box shows compressed area of southeastern New York.



Reconstruction of events at the end of the Devonian Period, when ancestral Africa had jammed into North America to close the Proto-Atlantic Ocean and produce the Acadian Mountains. Southeastern New York area of that time shown by dashed box.

Figure 13 - Reconstructed cross sections for the Medial Ordovician Taconic orogeny showing North America and an offshore volcanic chain on a collision course. (Isachsen, 1980.)

In this model, Cameron's Line marks a fundamental plate-tectonic boundary (suture) between continental [Layer IIA(W)] and oceanic realms [Layer IIA(E)] and thus may mark a root zone for much of the Taconic sequence in eastern New York state. The Hartland Formation (Complex) marks the deeply eroded roots of an uplifted accretionary complex marking the former trench into which the raw edge of North America was subducted. Merguerian's mapping in New York City and New England indicates that the allochthonous Manhattan Schist(s) are directly correlative with rocks of western Connecticut and Massachusetts along the east flank of the Berkshire and Green Mountains massifs and that various through-going geotectonic elements can be identified. (See Figure 12.)

Layer V: Mesozoic Rocks

In Connecticut, Mesozoic strata are exposed in three areas: (a) central Connecticut, in a belt extending northward from New Haven Harbor into central Massachusetts [underlain by the strata that filled the Hartford Basin; the whole belt has been named the Hartford basin (Cornet and Traverse, 1975; Olsen, 1974 ms.; Froelich and Olsen, 1985), but this is a trifle confusing, for the Hartford Basin in which the strata were deposited and the tilted- and eroded strata themselves are not the same things]; and two smaller areas underlain by strata thought to have been continuous formerly with those of the Hartford Basin: (b) the Pomperaug Valley belt; and (c) the Cherry Brook valley belt, Canton Center. In all of these three areas, the strata dip regionally toward the east. 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 Pomperaug River. We here restrict our discussion to the geology of the strata filling the Hartford Basin.

Strata Filling the Hartford Basin

Geologic Setting

The strata that filled Hartford Basin now underlie the Central Lowlands physiographic province of Connecticut (Figure 1, cover). These strata 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). The Hartford Basin was a fault-trough basin that subsided rapidly and was filled with sediment; in this basin, nonmarine depositional environments prevailed. Interstratified with the nonmarine sedimentary strata are the products of three episodes of mafic volcanism (Barrell, 1915; Longwell, 1933, 1937). The strata within the Hartford basin form an outcrop belt that extends northward from Long Island Sound in New Haven to central Massachusetts (Figure 14).

The sheets of mafic igneous rock ("trap rock" or "basalt" of most usage), which are exploited in many quarries, attracted the attention of the earliest geologist to study them (Percival, 1842). These sheets became the keys to understanding the stratigraphy and geologic structure only after the extrusive origin of some of them had been demonstrated, as is explained in the following section.

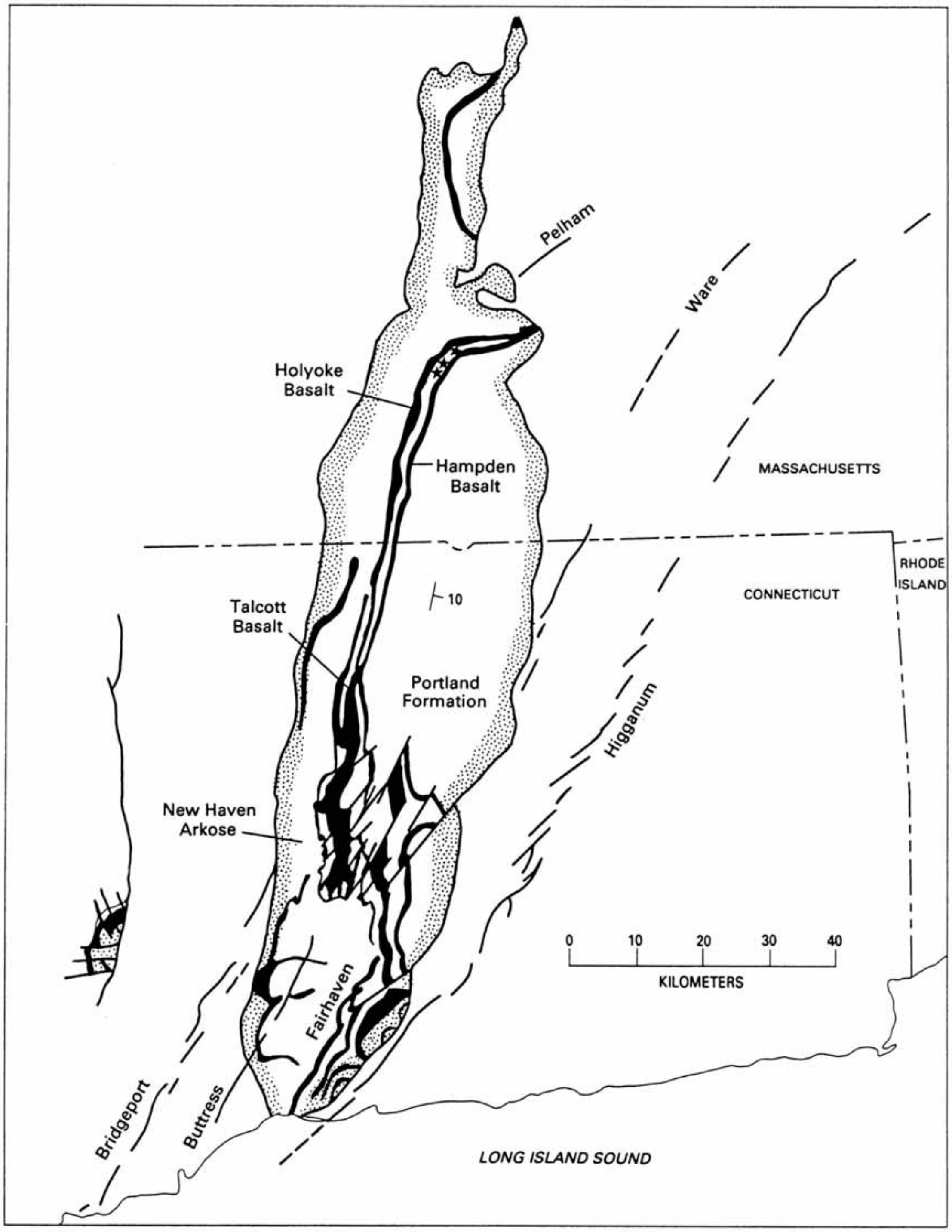


Figure 14 - Simplified geologic map of Hartford basin, central Connecticut and Massachusetts (margins stippled) and Pomperaug Valley outcrop belt (small area at lower left). All igneous rocks, both intrusive and extrusive, shown in black. (Philpotts,, 1985, Figure 20.1, p. 108.)

Geologic Significance of Extrusives: Keys to Stratigraphy and Geologic Structure

Although the sheets of mafic igneous rocks were accurately mapped by J. G. Percival (1842), all of them were considered by J. D. Dana (1871a; 1879; 1883) and others to be intrusives and thus not to be of any stratigraphic- or structural significance. The origin of these sheets of igneous rock became a major issue when William Morris Davis, then a young instructor at Harvard, showed that Percival's "Anterior," "Main," and "Posterior" trap sheets were extrusives and thus should be considered as part of the stratal succession just as if they were distinctive sandstones, for example. Davis thus became the father of the stratigraphy of volcanic rocks and used his insights gained from mapping the extrusive sheets to analyze the structure of the Newark strata of the Connecticut Valley belt (now the Hartford basin). (See W. M. Davis 1882a. 1882b, 1883, 1886, 1888a, b, 1889a, 1896, and 1898; Davis and Whittle, 1889.)

Building on Davis' results, W. L. Russell (1922) showed that rapid facies changes in the strata interbedded with the extrusive sheets could be demonstrated in southern Connecticut merely by walking out the basal contacts of these sheets of igneous rock and by observing how the particle sizes changed from boulder conglomerates close to the basin-marginal fault to mudstones a few kilometers distant from the basin-marginal fault (Figure 15). What Russell began was continued by C. R. Longwell (1922, 1928, 1932, 1933, and 1937); by Krynine (1950); by Digman (in Mikami and Digman, 1953); by Sanders (1958, 1960, 1963, 1968, 1970); by Lehmann (1959); by Sanders, Guidotti, and Wilde (1963); and by everyone else who has worked on the Newark strata in Connecticut since the 1960s.

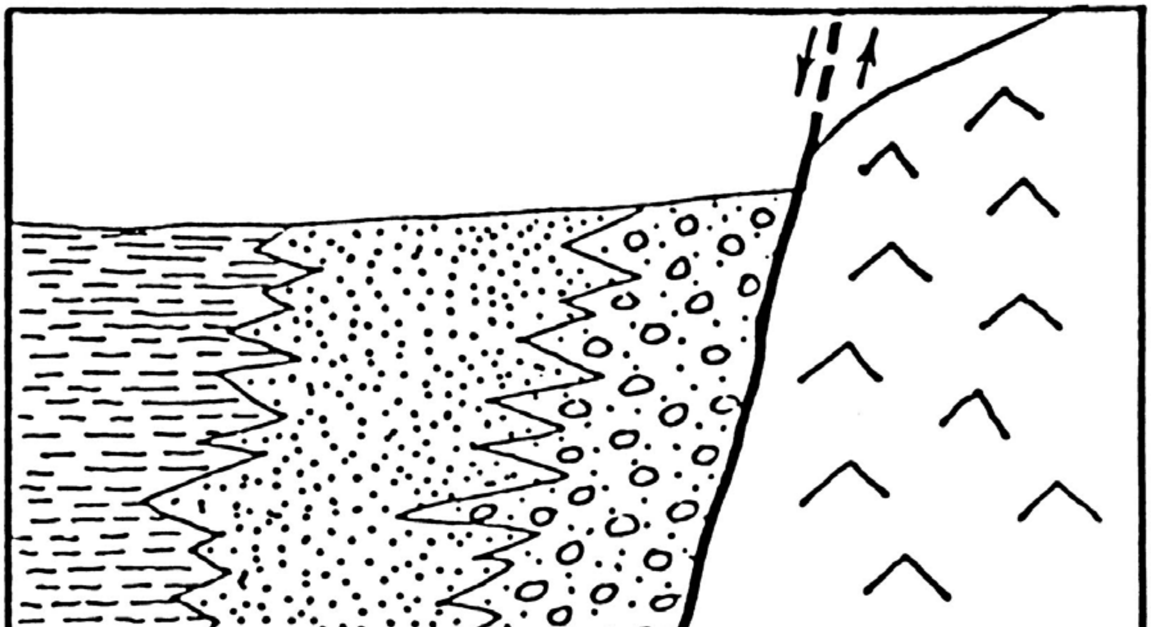


Figure 15 - Schmatic profile at margin of Hartford Basin showing rapid changes in texture of sediments from rudites adjacent to the basin-marginal fault to silts/muds farther away from this fault. (J. E. Sanders, 1965, fig. 7A, p. 298.)

Sedimentary Strata

The Newark strata filling the Hartford Basin consist of a thick succession that includes both sedimentary units and, as mentioned, sheets of mafic extrusive igneous rock. The strata have been subdivided into 7 formations. From base upward these are (S for sedimentary; V, for volcanic): New Haven Arkose (S), Talcott Formation (V and S), Shuttle Meadow Formation (S), Holyoke Formation (V), East Berlin Formation (S), Hampden Formation (V and S), and Portland Formation (S) (See Table 3).

New Haven Arkose

The New Haven Arkose was named for exposures in the eastern part of New Haven (Krynine, 1950). The formation consists of various interbedded coarse- and fine layers. In all, pink microcline derived from the feldspathic rocks of the Eastern Uplands is abundant. Two contrasting kinds of coarse layers are present: (a) massive and poorly sorted, and (b) laminated- and/or cross-laminated cyclic sequences that become finer upward. These are interlayered with sandy siltstones that are more or less devoid of layer-type structures, but locally are mottled in ways that suggest the sediments were reworked by burrowing organisms. JES infers that coarse layers of type (a) are products of subaerial debris flows on the surfaces of ancient fans and that those of type (b) are products of shallow, migrating stream channels. The thickness of the New Haven Arkose is not well known, but any reasonable attempt at reconstruction yields large numbers. JES thinks the correct thickness must be thousands of meters, perhaps even as much as 5 or 6 km. The New Haven Arkose rests nonconformably on the metamorphic rocks of the Western Uplands. The actual contact is visible at two localities: (1) Roaring Brook, Southington, where it overlies the Hartland Formation (Davis, 1898; Rice and Foye, 1927; Longwell, 1933; Wheeler, 1937; Krynine, 1950; Hubert, Reed, Dowdall, and Gilchrist, 1978; and Horne, McDonald, LeTourneau, and deBoer, 1993, p. P-18; a locality that for many years was "off limits" to geologists); and (2) north of the Wilbur Cross Parkway in Woodbridge (a northwestern suburb of New Haven), where it overlies the green rocks of the Maltby Lakes volcanics (Klein, 1968; Skinner and Rodgers, 1985). In both localities, the basal layers consist of coarse conglomerates. Throughout much of its extent, however, the New Haven Arkose has been faulted against the rocks of the Western Uplands (Wheeler, 1937; Fritts, 1962; 1963a, b, c).

Talcott Formation

The Talcott Formation consists of as many as four volcanic members separated by sedimentary members. In cuts along I-95 in East Haven and Branford, the two uppermost volcanic members are well exposed. The topmost volcanic member is a distinctive breccia in which angular chunks of basalt, some vesicular, display chilled margins against a matrix that includes sedimentary materials, some including fine pebbles. The next volcanic member down from the top is characterized by pillows, which indicates that the lava was extruded under water, probably on the floor of a large, deep lake. Associated with the pillowed member are other flow-type breccias and many irregular cavities that have been filled with a succession of minerals. (See descriptions by LaGanza, 1960.) JES reckons that the thickness of the Talcott Formation in southern Connecticut is about 1000 feet. In central Connecticut, however, the thickness is 200 feet or less. Still farther north along the main outcrop belt, the formation pinches out.

Shuttle Meadow Formation

The Shuttle Meadow Formation (Krynine, 1950) includes the sedimentary strata between the volcanic Talcott Formation below and the volcanic Holyoke Formation above. In most places where the Shuttle Meadow Formation has been mapped, the plain truth is that it designates a covered interval between two prominent topographic ridges capped by the volcanic formations. As with all the sedimentary units, particle sizes are small in localities well removed from the basin-marginal fault, but coarse in localities adjacent to this fault. At the type locality, the Shuttle Meadow Formation consists of shales and fine sandstones, clearly products of deposition in or around the margins of an ancient lake. In East Haven, the basin-marginal rudites of the Shuttle Meadow Formation display characteristics of fans. In addition, they contain boulders of vesicular basalt. Such boulders imply that the underlying Talcott volcanic members were being elevated and eroded and mixed with the usual feldspathic debris coming from the Eastern Uplands. The thickness of the Shuttle Meadow Formation in the Branford quadrangle is about 1500 feet. Farther north, however, the thickness is only about 300 feet. The details of this change in thickness are not known, but constitute part of the evidence on which the existence of the Gaillard graben was inferred (Sanders, Guidotti, and Wilde, 1963).

Holyoke Formation

The Holyoke Formation was originally named the Holyoke Basalt (Emerson, 1898) for the resistant unit underlying the Holyoke Range in central Massachusetts. The name was extended into Connecticut by Rodgers and others (1956, 1959). The Holyoke Formation is the middle and thickest of the three units of extrusive mafic igneous rock that are interbedded with the Newark sedimentary strata. The Holyoke Formation is the "Main" trap sheet of Percival (1842) and the "Middle" or "Main" flow of various reports by W. M. Davis (for example, 1898), and the "Middle lava flow" of Krynine (1950, p. 32). The thickness of the Holyoke Formation is about 600 feet.

Emerson and most subsequent authors have referred to the Holyoke as consisting of basalt. We presume that this usage reflects the concept that the extrusive igneous rock formed by the cooling of a subaerial lava flow will be fine textured because of the well-known relationship between texture of an igneous rock and rate of cooling. Because a subaerial lava flow is thought to cool quickly, nearly every geologist would expect that the texture of the resulting rock would be aphanitic, and therefore, if the rock is mafic, that it would be a basalt.

A further point from the literature about the texture is whether or not the rock is porphyritic. The presence of porphyritic rocks among the mafic igneous rocks associated with the Newark strata in the Hartford basin was first published by Fritts (1963). Recent interest in the mafic igneous rocks associated with the Newark strata has emphasized their chemical compositions. In contrast with the "distinctly porphyritic" Hampden (uppermost of the three extrusive units), the Holyoke has been described as being "almost totally aphyric, containing only widely scattered plagioclase phenocrysts set in a groundmass of intergranular plagioclase, augite, pigeonite, and magnetite, with minor insterstitial clear glass or granophyre" (Philpotts and Reichenbach, 1985, p. 1132).

According to the sizes of the crystals, the Holyoke contains a complete spectrum of varieties ranging from a gabbro pegmatite to aphanitic basalt. The most-abundant rock type is the medium-textured variety refered to as dolerite. If a single rock name is to be applied to the Holyoke, then it should be one referring to the variety that is distinctly coarser than basalt. We suppose that the reason this has not been done is that many petrologists reserve the use of terms such as dolerite and gabbro for plutonic rocks as opposed to volcanic rocks. In making this connection between mafic rocks of intermediate- and coarse texture and occurrence in plutons, the supposition is being codified that plutons cool slower and thus the textures of their rocks will always be coarser than those of extrusives.

East Berlin Formation

The East Berlin Formation was named by E. P. Lehmann (1959) for the sedimentary strata lying above the Holyoke volcanic formation and below the Hampden volcanic unit. The East Berlin Formation displays the same general relationships as the Shuttle Meadow Formation: fine-textured strata, probable lake deposits, away from the basin-marginal fault, and coarse debris close to this fault.

Hampden Formation

The Hampden is the upper volcanic unit. Not much more needs to be said about this formation here other than it consists of at least two flow units separated by sedimentary strata of variable thickness. The three volcanic formations of the Hartford basin-filling complex match very closely with the three extrusives complexes of New Jersey (the First-, Second-, and Third Watchung basalts, named by P. E. Olsen (1980a) the Orange Mountain, Preakness, and Hook Mountain formations, respectively.

Portland Formation

The Portland Formation (Krynine, 1950) refers to all the sedimentary strata (and covered intervals!) overlying the Hampden Formation. The Portland Formation and New Haven Arkose form outcrop belts having mirror-image width relationships. In southern Connecticut, the great width is underlain by the New Haven Arkose. In central Connecticut, the widest part of the Newark outcrop belt is underlain by the Portland Formation. The Portland Formation consists of the usual sedimentary strata: fine-textured lake deposits, medium sandstones (those quarried near Portland, Connecticut, are known as "Connecticut brownstones") and, adjacent to the basin-marginal fault, coarse conglomerates.

Paleogeography of Newark Basin

The general paleogeographic setting of the Newark Basin was first set forth by Joseph Barrell (1915). In general, most subsequent workers until the 1970s accepted Barrell's general interpretation without much modification. Sanders (1968a, b) made the case for inferring that many of the Newark strata had been deposited in lakes, including some that were large and deep. The details of the lacustrine setting have been much embellished by Paul Olsen (1984 ms., and subsequently). Based on the results of the core-drilling program carried out in the Newark-basin filling strata in central New Jersey, Olsen has reconstructed not only the history of cyclic changes in water depths in the former lakes, but has also related the paleogeographic setting to the position of the former Equator and related global-scale wind belts of the tropical regions. Of particular importance is the annual migration between the Tropic of Cancer and Tropic of Capricorn of the Intertropical Convergence Zone (ITCZ), with associated reversals of wind directions in parts of the Trade-Wind zones and migration of zones of seasonal torrential rainfall (Friedman, Sanders, and Kospaska-Merkel, 1992).

Horne, McDonald, LeTourneau, and deBoer (1993) present the interpretation that the finding of western-shore lacustrine deposits implies that significant amounts of the strata filling the Hartford Basin were derived from the west (they assert, from the Western Highlands), and therefore that the former extent of the basin during the Triassic- and Jurassic periods was not significantly greater than now. In our judgment, their interpretation too-lightly dismisses the evidence for the mid-Jurassic episodes of deformations that ended the period of accumulation of strata in the Hartford Basin. We mention this point in a following paragraph.

Geologic Structure of the Hartford Basin-Filling Strata

To a first approximation, the geologic structure of the Hartford Basin can be characterized as an eastward-dipping homocline bounded on the west by pre-Newark (mostly Paleozoic) metamorphic rocks of the much-elevated basin floor and separated from other Paleozoic (and Precambrian) metamorphic rocks of the basin wall by a major fault (Figure 16). In Connecticut, this fault has not been formally named, but it is analogous to the Ramapo Fault in New Jersey that bounds the Newark basin along its west- and northwest margin. (We refer you to On-The-Rocks Trip #5.) Here, we shall be referring to the Connecticut fault as the basin-marginal fault of the Hartford basin.

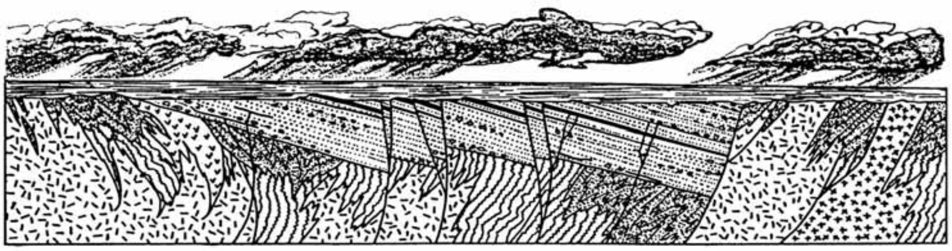


Figure 16 - Profile-section through Hartford basin in latitude of central Connecticut showing regional eastward dip of the strata and the postdepositional faults. (Barrell, 1915, fig. 2.)

Because basin-marginal rudites are distributed through a vertical range of at least several thousand of meters of sedimentary strata (Russell, 1922; Longwell, 1922, 1928), one can infer that topographic relief was maintained. These relationships imply that the basin-marginal fault was intermittently active for the time during which the coarse strata accumulated.

The fact that the outcrops 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, as in Figure 16, is not altogether accurate. Instead of being strictly linear, as 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, these folds have been classified as transverse folds (Wheeler, 1939). In the Hartford Basin, the sizes of of these transverse folds increase systematically northward. From south to north, the names of these transverse folds in Connecticut are: Saltonstall syncline, North Branford anticline, Totoket syhncline, Durham anticline, Cedar Mountain (or Rocky Hill) anticline, and Springfield syncline (Figure 17).

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. JES has carried this analysis one step further by using the displacement of the vertical axial planes of some of these transverse anticlines to infer the existence of strike-slip faults (Sanders, 1962). 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; 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 JES' minority-of-one view that the horizontal offsets of the vertical axial planes 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.

The abrupt ending of many folds having vertical axial planes 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.

Our purpose in mentioning the folds is to explain the contrast in locations with respect to the basin-marginal fault of the curvilinear ridges underlain by the eroded edges of the resistant sheets of mafic extrusive igneous rock, but particularly of the Holyoke Formation. In southern Connecticut, these ridges are situated along the east side of the Newark outcrop, close to the basin-marginal fault. For example, the map distance from the ridge underlain by the Holyoke Formation to the basin-marginal fault ranges from 3 km in the axis of the Saltonstall syncline to 5 km in the axis of the Totoket syncline, to 10 km in the axis of the Middletown syncline. Moreover, in these three synclines, some of the ridges end toward the southeast by being cut off at this fault. Accordingly, the width of outcrop of the New Haven Arkose far exceeds that of the Portland Formation (Figure 18). To a certain degree, the width of outcrop is related to the preserved thickness of the strata of these two formations. That is, in southern Connecticut, the

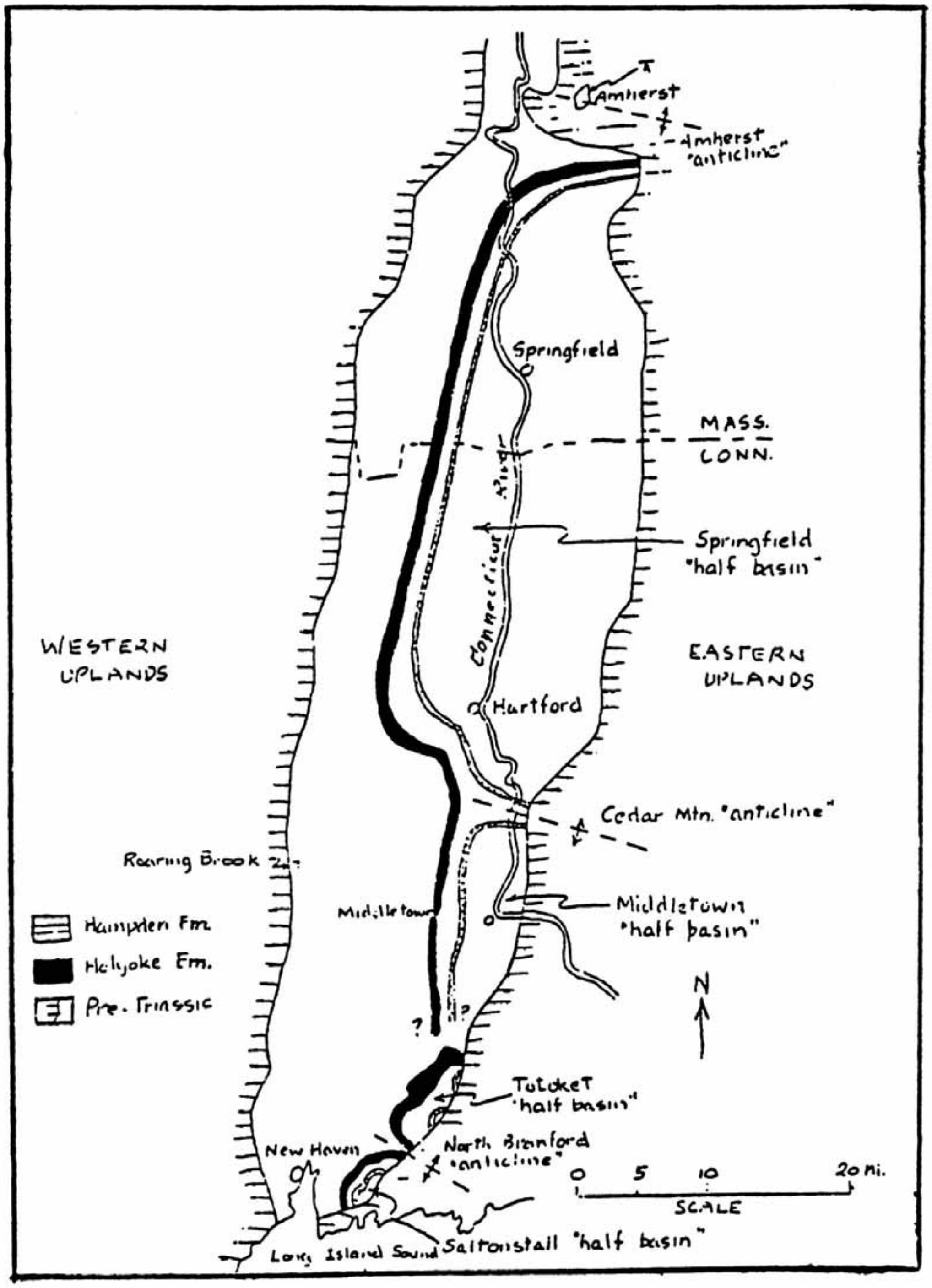


Figure 17 - Schematic geologic map of Hartford basin showing outcrop pattern of Holyoke and Hampden formations as they might have appeared after the strata had been tilted, transversely folded, and eroded, but before they had been displaced on post-fold faults. (Sanders, 1958, Fig. 2, p. 7.)

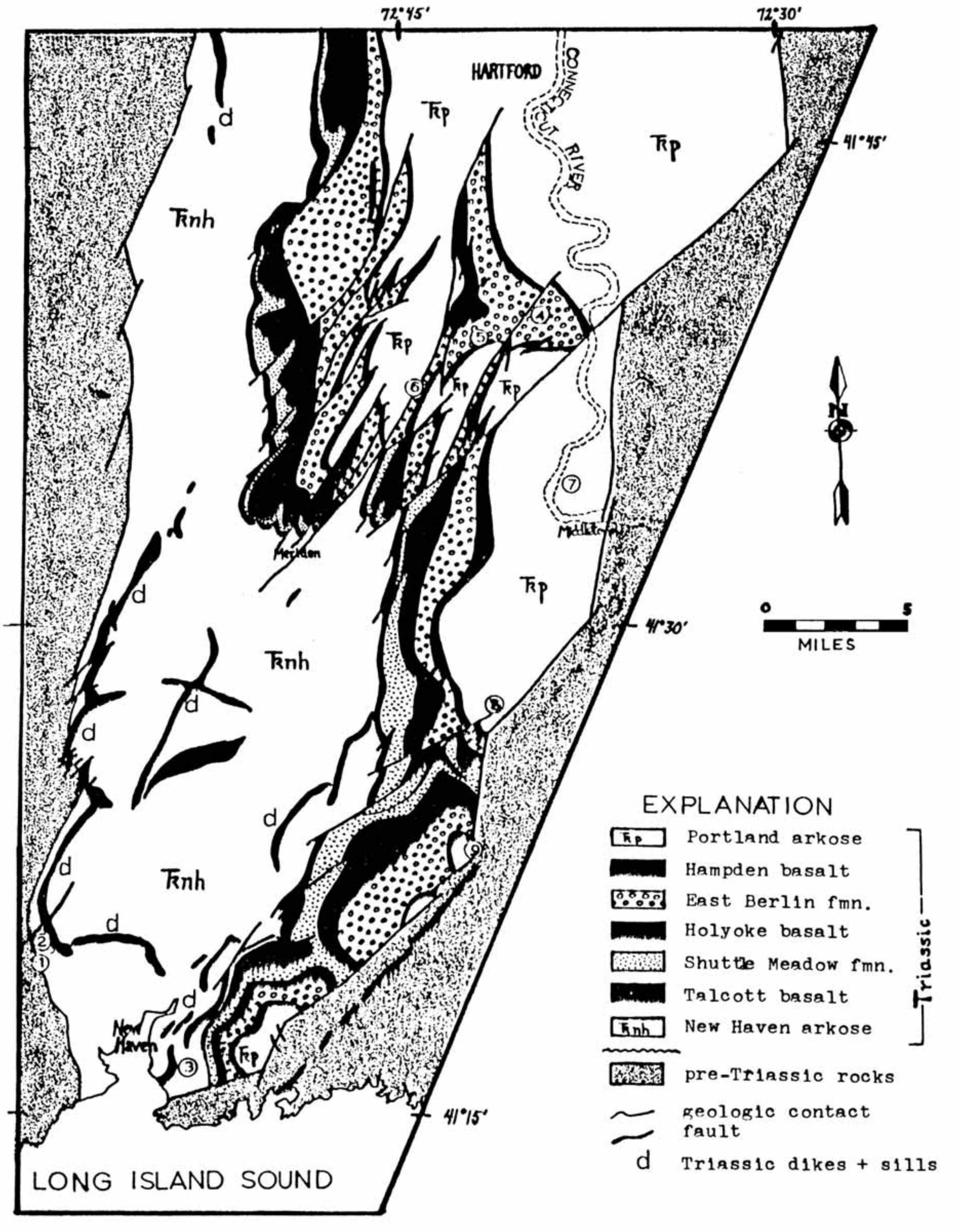


Figure 18 - Generalized geologic map of Newark strata in the Hartford basin, south-central Connecticut. Compare widths of outcrop of the New Haven and Portland formations in the latitude of New Haven with those in the latitude of Hartford. (G. deV. Klein, 1968, Fig. 1, p. C-1 2.)

width of outcrop of the New Haven Arkose averages about 15 km and the thickness of this formation, although not exactly known, clearly must amount to several thousands of meters, and possibly may be as much as 5 km. By contrast, the width of outcrop of the Portland Formation ranges from about 1 km in the Saltonstall syncline to about 6 km in the Middletown syncline. This indicates that the preserved thickness of the Portland Formation in southern Connecticut ranges between a figure of only a few hundred meters, possibly as much as 1 km, and about 3 km.

In central Connecticut, these relationships are reversed. From the Hanging Hills in Meriden northward, the ridges underlain by the tilted edges of the extrusive sheets lie along the west side of the Newark outcrop. Using the outcrop belt of the Holyoke Formation as a reference, the distances from the resistant ridge to the basin-marginal fault are about 17 km in localities south of the latitude of Rocky Hill and about 24 km north of the latitude of Hartford. The width of the outcrop belt of the New Haven Arkose is about 9 km. The thickness of the New Haven Arkose here is not easy to determine; the unit has been faulted against the pre-Newark rocks to the west. Its thickness could be the same as in southern Connecticut, but outcrop data do not support any reliable estimates. By contrast, the width of outcrop of the Portland Formation north of Hartford is about 21 km. The thickness of Portland Formation preserved clearly could be many times greater than it is in southern Connecticut. Outcrops are scattered and the formation may be duplicated by the Hartford Fault. Seismic profiles have been made in connection with evaluations of petroleum possibilities, but we have not yet had the privilege of looking at any of these.

LAYER VII: QUATERNARY SEDIMENTS

Quaternary sediments consist of Pleistocene glacial sediments and Holocene sediments as described below.

Glacial Deposits

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 discussed in the New York City region (Manhattan trip and Staten Island trip). 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 NW-SE; and the younger, Hamden till, with flow NNE-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). JES thinks these end moraines are the terminal moraines for the glacier that deposited the Hamden till.

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 thinned to the point where its gravity-driven outflow ceased. No series of recessional moraines resulted. Instead, outwash sand and gravel blanket the countryside.

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 (Figure 19). 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 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 betgween 16,500 and 15,500 b. p. (JES thinks this assignment is probably too old by as much as 3,000 years, but that is another story.)

Flint (1930, p. 101) cited Dana (1884, p. 10) 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 20) and from exposures in the Quinnipiac Valley brick pits (where a thickness of about 20 feet is seen, Figure 21).

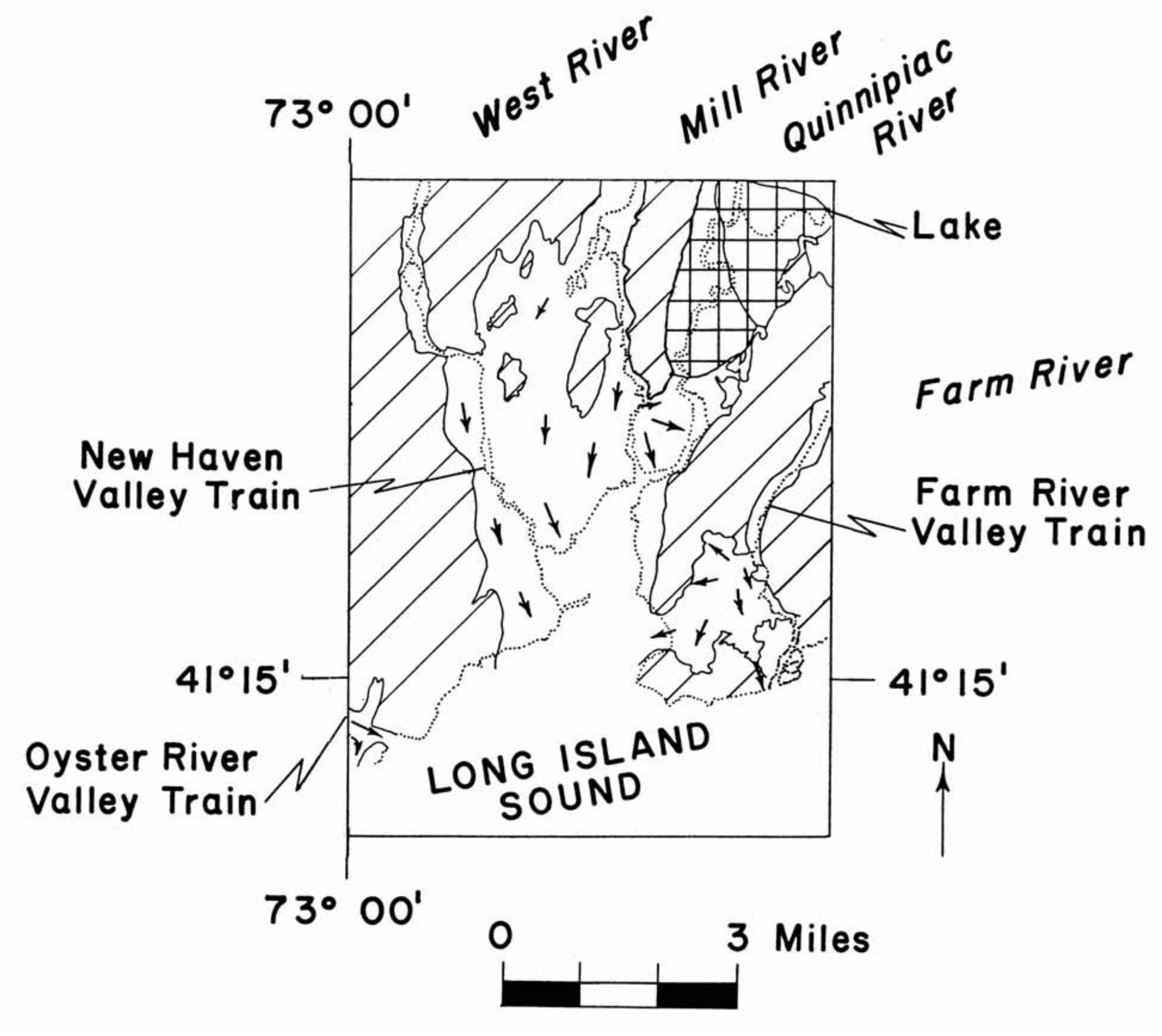


Figure 19 - Map of outwash valley trains (composed of sand and silt) in New Haven area and their locations with respect to the proglacial lake in the southern Quinnipiac Valley. (J. E. Sanders, 1989 ms., based on mapping by R. F. Flint.)

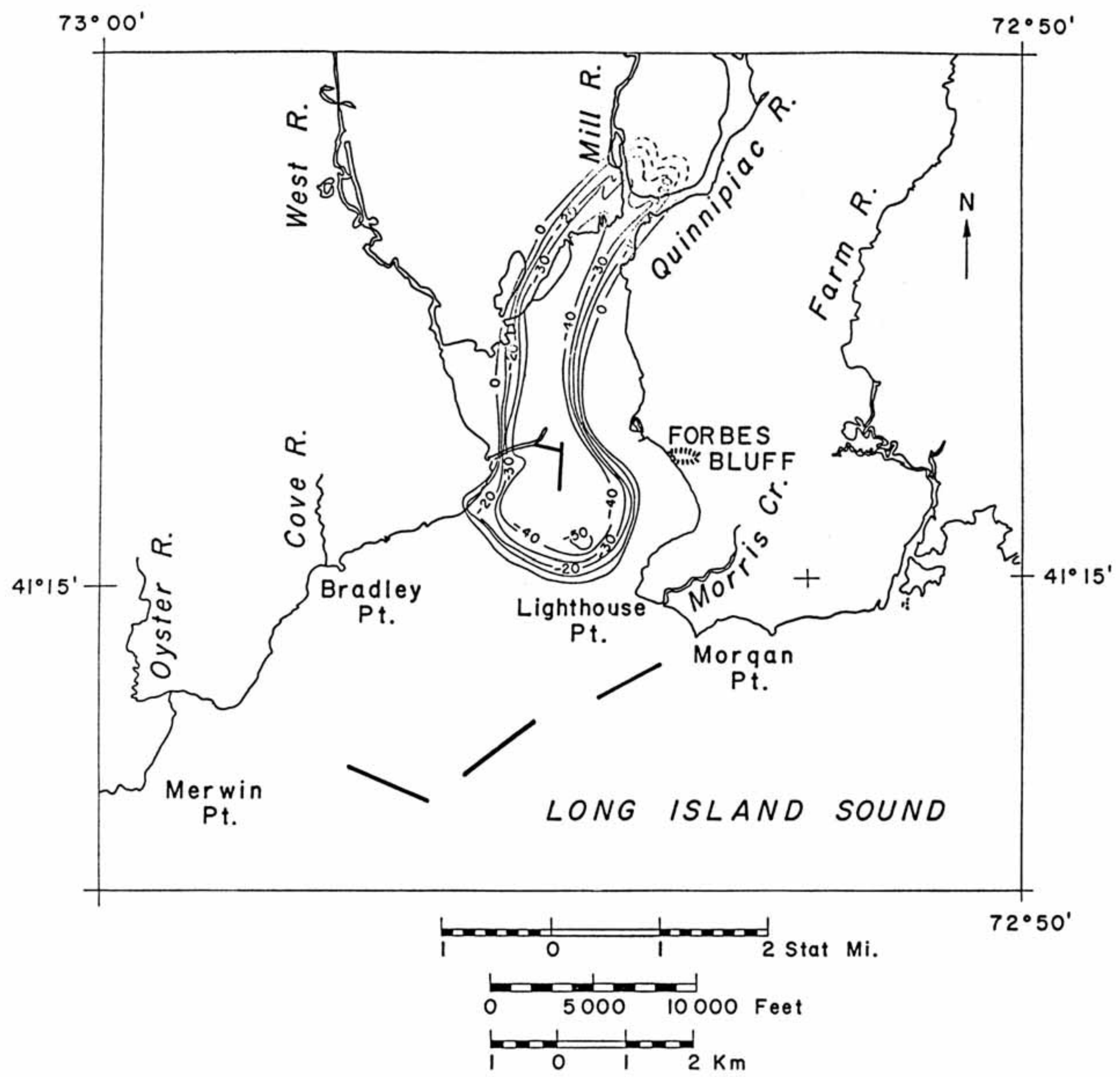
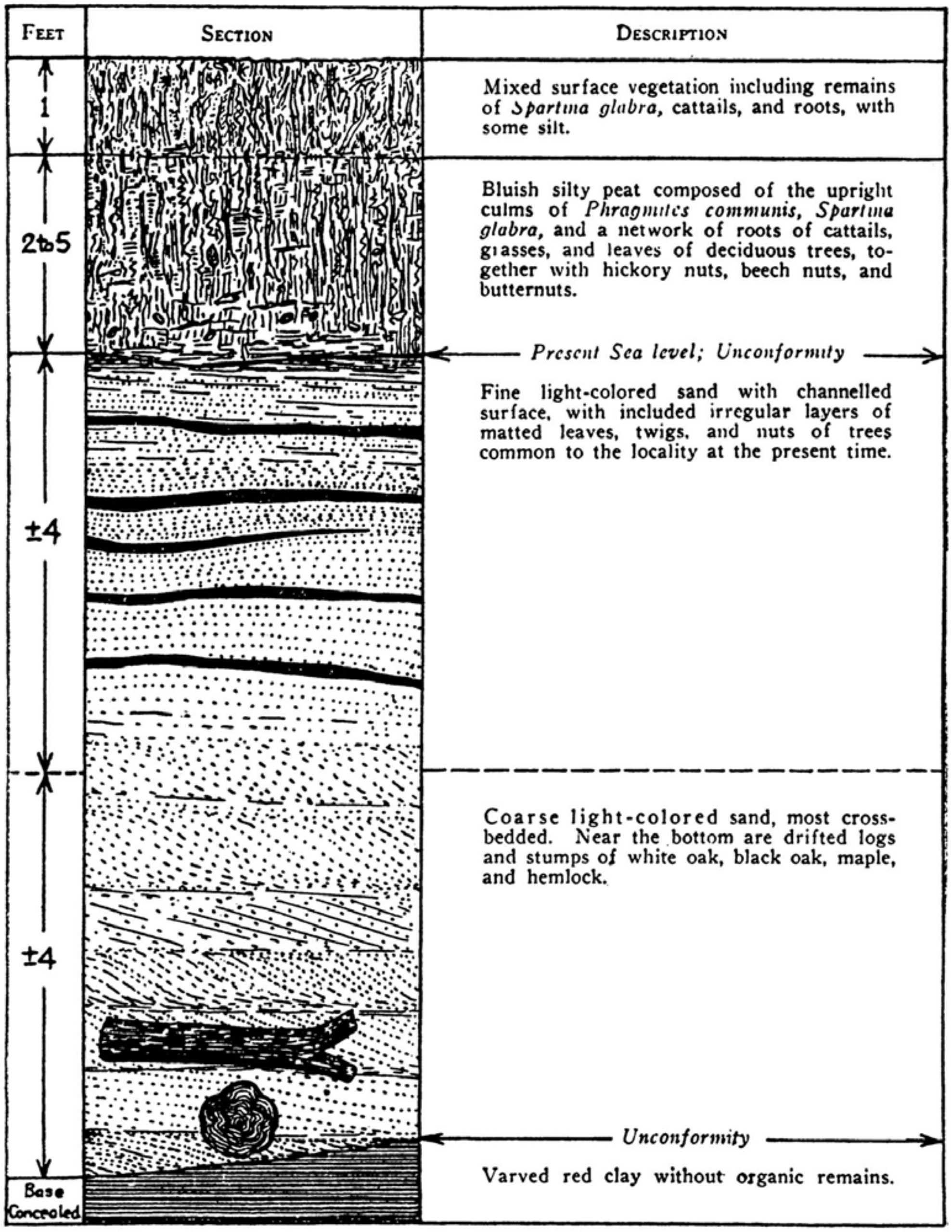


Figure 20 - Map of New Haven harbor showing thickness of Holocene estuarine silt. (J. E. Sanders, 1989 ms.)



Mixed surface vegetation including remains of *Spartina glabra*, cattails, and roots, with some silt.

Bluish silty peat composed of the upright culms of *Phragmites communis*, *Spartina glabra*, and a network of roots of cattails, grasses, and leaves of deciduous trees, together with hickory nuts, beech nuts, and butternuts.

Fine light-colored sand with channelled surface, with included irregular layers of matted leaves, twigs, and nuts of trees common to the locality at the present time.

Coarse light-colored sand, most cross-bedded. Near the bottom are drifted logs and stumps of white oak, black oak, maple, and hemlock.

Varved red clay without organic remains.

Figure 21 - Stratigraphic of Holocene sediments in Stiles clay pit, opposite Montowese, Quinnipiac Valley, Connecticut. (R. W. Brown, 1930, in R. F. Flint, fig. 42, p. 263.)

DRAINAGE HISTORY

The drainage history of Connecticut has resulted from several complex episodes of uplift and valley erosion, some of which antedated the arrival of the first Pleistocene continental glacier and some of which were related to periods of drainage re-arrangement that accompanied the melting of the glaciers.

As in the New York City region, the oldest surviving evidence for ancient drainage is contained in the Newark Supergroup. 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.

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. 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 (1963). 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 22 and 23.) 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. This depression was in existence when the Pleistocene glaciers arrived. This Pliocene time of elevation and erosion is probably as far back as it is possible to trace the history of most modern valleys. Figure 24 shows a series of four stages in the drainage history of northeastern United States according to Veatch (1904). Refer to Table 4 for our correlation of the Pleistocene units on Long Island that show the relationships of the post-Manneto and Vineyard erosion intervals.

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). JES thinks this U-shaped valley was carved by one of the glaciers that flowed from the NW to the SE and was diverted to nearly W-E flow by the escarpment facing the inner cuesta lowland at the eroded edge of the coastal-plain strata.

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.

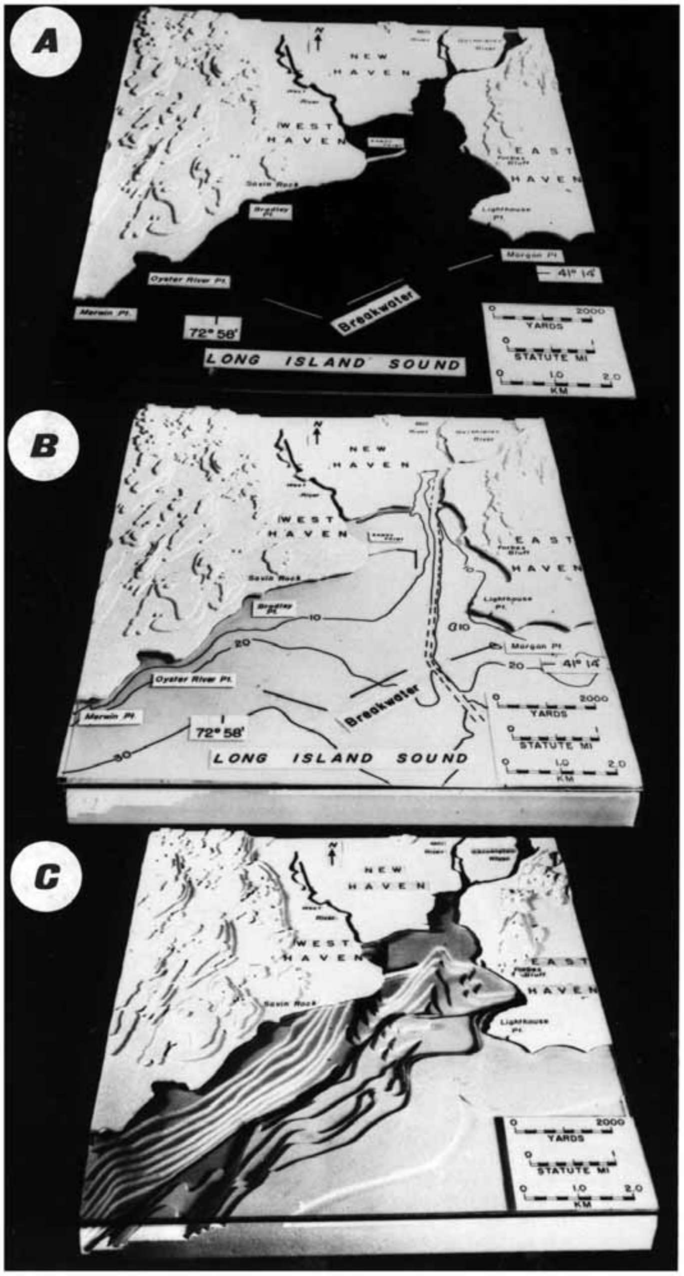


Figure 22 - Photographs of styrofoam model of New Haven harbor and vicinity showing contrast between modern relief and buried valleys. (Model built by Topofoam, Inc., New York City, supported by U. S. Office of Naval Research at Hudson Laboratories of Columbia University, Dobbs Ferry, New York.)
A. View 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 bedrock walls of buried valleys; each step equals 100 feet. Valley 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.)

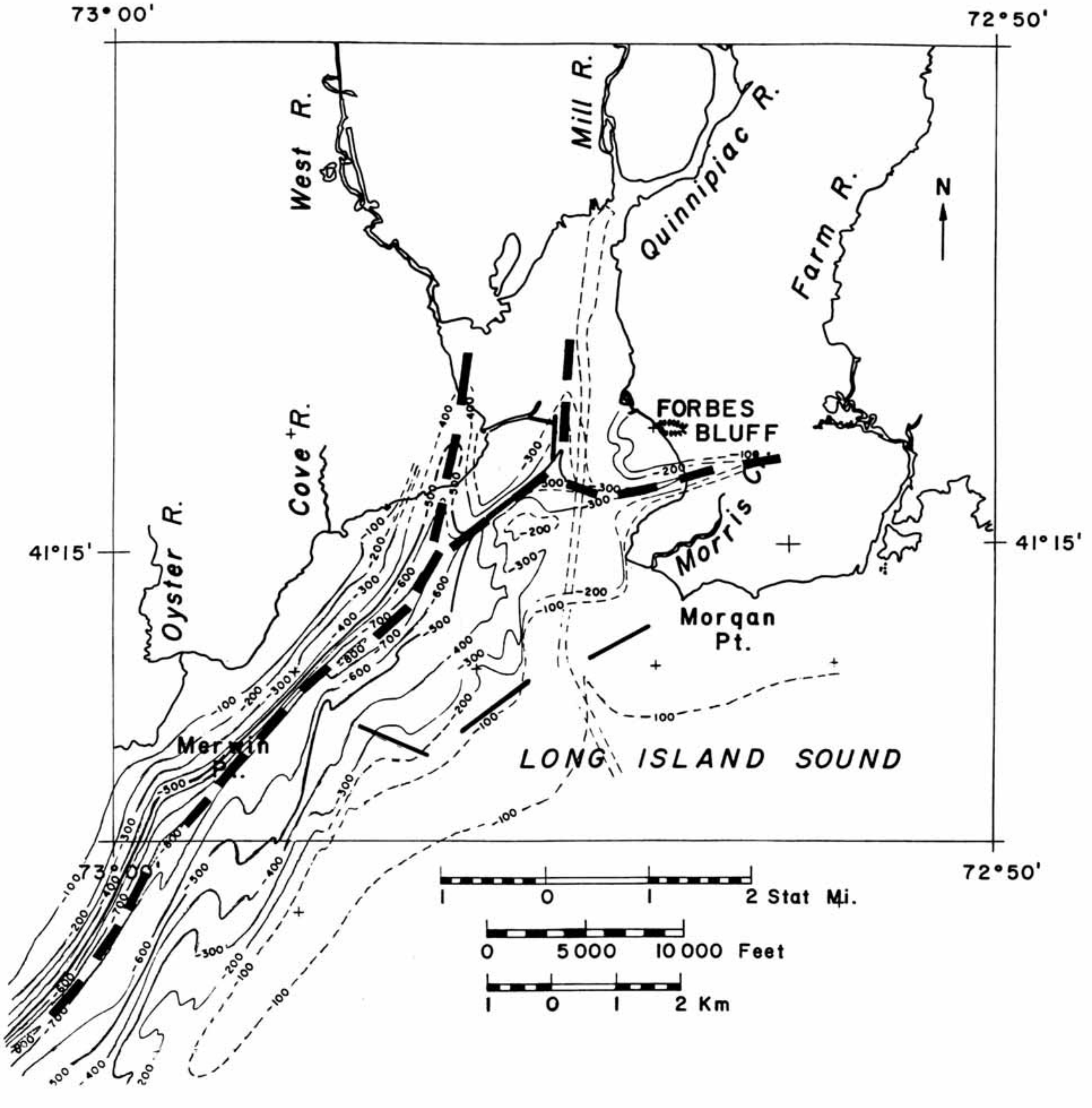


Figure 23 - Map of New Haven harbor showing location of talweg of buried valleys (thick dashed lines), based on continuous seismic-reflection profiles using Bolt Associates 1-cubic-inch air-gun sound source. (J. E. Sanders, 1989 ms.)

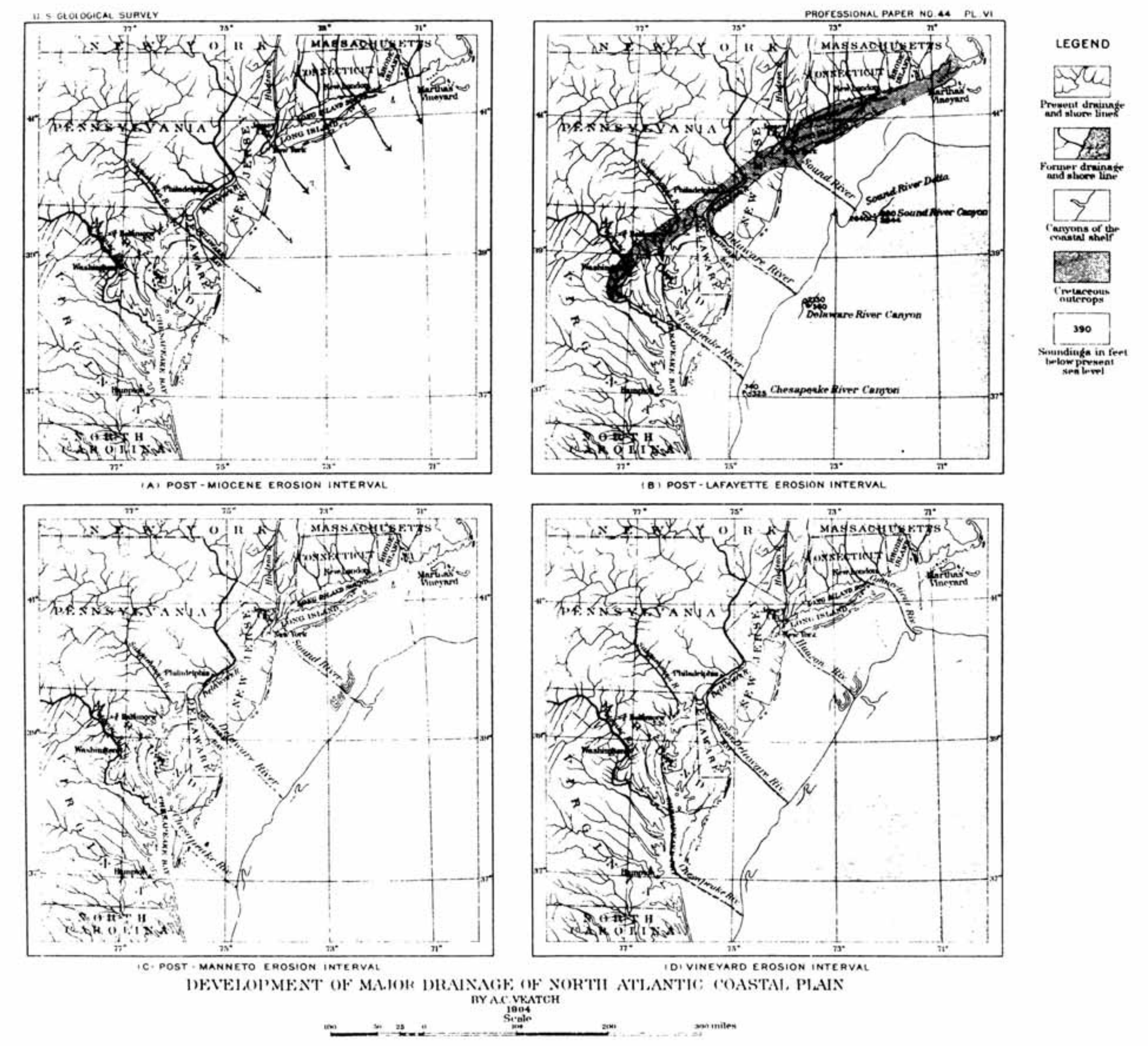


Figure 24 - Maps showing inferred drainage at four episodes in post-Miocene time. (A. C. Veatch 1904, plate VI.)

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. JES thinks that some of the new drainage may have been initiated on the top of the ice itself, so that 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. This 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.

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 JES that these features were eroded by a thick glacier whose flow direction was determined by the slope on the top of a thick 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 JES thinks the minimum number is 2.

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). In these lakes were deposited varved sediments that Antevs (1922) used to assemble a chronology of glacial retreat.

So much for the geologic background. We now turn to the specifics of today's trip, starting with the objectives.

OBJECTIVES

1) To collect minerals from the Case beryl prospects in Portland, Connecticut.

2) To examine the stratigraphy of the Hartford Basin of central Connecticut.

3) To discuss the structure of the Hartford Basin.

4) To locate and discuss glacial features, and,

5) To avoid being bitten by ticks or mosquitos.

LIST OF LOCALITIES TO BE VISITED

Stops 1 through 4, in central Connecticut are shown on the cover, Figure 1.

Stop 1: Case beryl prospects, Portland, Connecticut.
Stop 2: Rocky Hill Dinosaur State Park.
Stop 3: New roadcuts, CT Route 9, Cromwell.
Stop 4: New roadcuts, CT Route 372. East Berlin.

ROAD LOG AND DESCRIPTIONS OF INDIVIDUAL LOCALITIES ("STOPS")

[BEGIN "FLOATING" SEGMENT OF ROAD LOG]

[3.0] MP NE3 on R.
[3.5] Enter Westchester County.
[4.0] MP NE4 on R.
[4.4] Exposure on L of foliated schist of Hutchinson River Group (Hartland).
[6.5] Exposure on L, just before tolls, of metasedimentary rocks and intrusives with gentle west-dipping foliation.
[6.6] Toll Booth. Pay up.
[8.3] Rocks exposed on L.
[8.5] Passing Exit 18A (Fenimore Road, Mamaroneck and Larchmont).
[8.9] Rocks exposed on L.
[9.2] More exposures on L.
[11.1] Exposure on L then on R.
[11.4] In rocks exposed on L, foliation dips steeply.
[l2.5] Passing Exit 19 (Playland in Rye, New York).
[12.9] Rocks exposed on R.
[13.0] Steeply dipping micaceous gneiss exposed on L.
[13.7] Rye, New York Metro North Station on R.
[14.4] Exposure on R.
[14.5] Exposure on R.
[15.1] Enter Connecticut.
[16.0] Exposure of Oh on R.
[16.3] Exposure of Oh on L.
[17.1] Newly opened cut on R of steeply dipping schist.
[18.5] Passing Exit 4 (Indian Field Road, Cos Cob).
[20.3] Passing Exit 5 (Riverside, Old Greenwich).
[21.0] Passing Exit 6 (Harvard Avenue, Stamford).
[21.8] Passing Exit 7 (CT Route 137 North, Greenwich Avenue).
[23.6] Passing Exit 9 (US 1 and CT Route 106, Glenbrook).
[25.0] Passing Exit 10 (Noroton and Noroton Heights).
[25.7] Passing Exit 11 (Darien).
[26.3] Passing Exit 12 (CT Route 136, Rowayton).
[26.6] Passing ramp on R for Service/Rest area (MacDonalds/Mobil).

[END OF "FLOATING" SEGMENT OF ROAD LOG.]

Real road log starts at zero at ramp where traffic from rest stop re-enters I-95.

[0.0] Passing ramp where traffic from service area rejoins I-95.
[0.6] Passing Exit 13 (Post Road, US 1) on R.
[1.6] Exposures on R; Otf + Og on J. Rodgers 1985 CT map.
[1.9] Exposures on R; low-dipping metamorphic fabrics.
[2.2] Passing Exit 14 (to South Norwalk).
[2.25] Exposures on R; low-dipping schist.

[2.3] Passing Exit 15 (US Route 7, Norwalk and Danbury).
[3.3] Passing Exit 16 on R (East Norwalk).
[4.4] MP 17 on R.
[4.5] Exposure of felsic gneiss on R.
[5.1] Passing Exit 17 on R (CT Routes 33 and 136; Westport, Saugatuck).
[5.3] More felsic gneiss exposed on L.
[5.4] MP 18 on R.
[5.7] Crossing Saugatuck River.
[7.4] MP 20 on R.
[7.5] Passing Exit 18 on R (Sherwood Island State Park, Public Beach).
[7.9] Exposures of low-dipping, brown-weathering muscovitic schist on R and L (Hartland Formation).
[8.5] MP 21 on R.
[9.1] More coarse muscovitic Hartland Schist on R.
[9.4] More of same.
[9.6] MP 22 on R.
[10.2] Passing Exit 19 on R (Center Street, Southport).
[11.1] Gray schist on L; DUKE outcrop-removal operation in progress; schist going bye-bye.
[11.7] Passing Exit 21 on R (Mill Plain Road); no Exit 20.
[12.2] Passing Exit 22 on R (Round Hill Road; also Rest Stop and Service Area MacDonalds & Mobil).
[12.5] MP 25 on R.
[13.3] Passing Exit 23 on R (Kings Highway, US Route Route 1).
[14.0] Passing Exit 24 on R (Black Rock Turnpike).
[14.6] MP 27 on R.
[14.7] Passing Exit 25 on R (State Street).
[15.8] Passing Exit 26 on R (Wordin Avenue).
[16.5] Passing Exit 27 on R (Lafayette Blvd., downtown Bridgeport, and Barnum Museum).
[16.7] Passing Exit 27A (CT Routes 25 and 8, Trumbull and Waterbury).
[16.8] MP 29 on R.
[17.4] Passing Exit 28 on R (East Main Street).
[17.7] MP 30 on R.
[17.9] Passing Exit 29 on R (Stratford Ave.); view to R of Long Island Sound.
[18.7] Passing Exit 30 on R (Lordship Blvd., CT Route 113).
[19.0] MP 31 on R.
[19.7] Passing Exit 31 on R (Honeyspot Road).
[20.0] MP 32 on R.
[20.5] Passing Exit 32 on R (West Broad Street, Stratford).
[20.8] MP 33 on R.
[21.6] Passing Exit 33 on R (US 1, CT Route 110, Ferry Blvd., Devon).
[21.9] MP 34 on R.
[22.4] Crossing over Housatonic River.
[22.9] MP 35 on R.
[23.2] Passing Exit 34 on R (US 1, Milford).
[23.7] Passing Exit 35 on R (School House Road, BIC Drive).
[23.9] MP 36 on R.

[24.5] Passing Exit 36 on R (Plains Road).
[25.2] MP 37 on R.
[25.4] Passing Exit 37 on R (High Street).
[25.7] Passing Exit 38 on R (CT Route 15, Merritt Parkway and Wilbur Cross Parkway).
[27.0] Passing Exit 39A on R (US 1, South). Chlorite schist, lower part of Maltby Lakes volcanics (Ordovician) exposed by ramp on R.
[27.2] Passing Exit 39B on R (US 1, North).
[27.3] MP 37 on R.
[28.0] Passing Exit 40 on R (Old Gate Lane, Woodmont Road).
[28.2] Exposures of Allingtown metavolcanics (Ordovician) on R.
[28.6] More of same exposed on R.
[28.8] More of same exposed on R.
[28.9] Ditto.
[29.1] Passing Service area on R (MacD's and Denny's).
[29.2] Ditto.
[29.3] MP 41 on R.
[29.7] More Allingtown metavolcanics on R.
[29.8] Passing Exit 41 on R (Marsh Hill Road, Orange).
[29.9] Exposures on R of Oronoque Schist (Ordovician).
[30.2] MP 42 on R.
[32.2] Passing Exit 42 on R (CT Route 162, Saw Mill Road, West Haven).
[32.3] MP 44 on R.
[32.9] Exposures on both sides of Oronoque Schist (Ordovician).
[33.0] Passing Exit 43 on R (Downtown West Haven).
[33.3] MP 45 on R. At the bottom of the hill, we leave the Western Uplands province of Connecticut on which we have been traveling since we entered the state, and cross into the Central Valley province that is underlain by the Upper Triassic-Lower Jurassic basin-fill strata of the Hartford basin. The modern lowland (Connecticut Valley) has been formed because the basin-fill sedimentary strata are not generally resistant to erosion. Thus, the modern lowland generally coincides with an area that was low during the early Mesozoic Era and thus was receiving sediments eroded from its elevated margins. By contrast, the associated sheets of mafic igneous rocks (both intrusive and extrusive; collectively known as "trap" rock), do resist erosion and thus tend to cap ridges. Because the basin-filling strata have been tilted (generally to the east in the Connecticut Valley outcrop belt in contrast to the regional tilt to the west in the Newark outcrop belt), the sheets of igneous rock cap strike ridges. (See Figure 16.)

[34.0] View ahead and to R of New Haven harbor. Under the water of this harbor, the rocks of the Eastern Uplands are faulted against 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. (See Figures 22 and 23 and discussion under Drainage History.) The ridges projecting above the lowland ahead are held up by resistant mafic igneous rock (Figure 25). In some (such as West Rock, the Palisades analogue, and East Rock, in New Haven) the igneous rocks are intrusives. In others, including the linear ridges in the far distance (the Watchung analogues), the igneous rocks are extrusives.

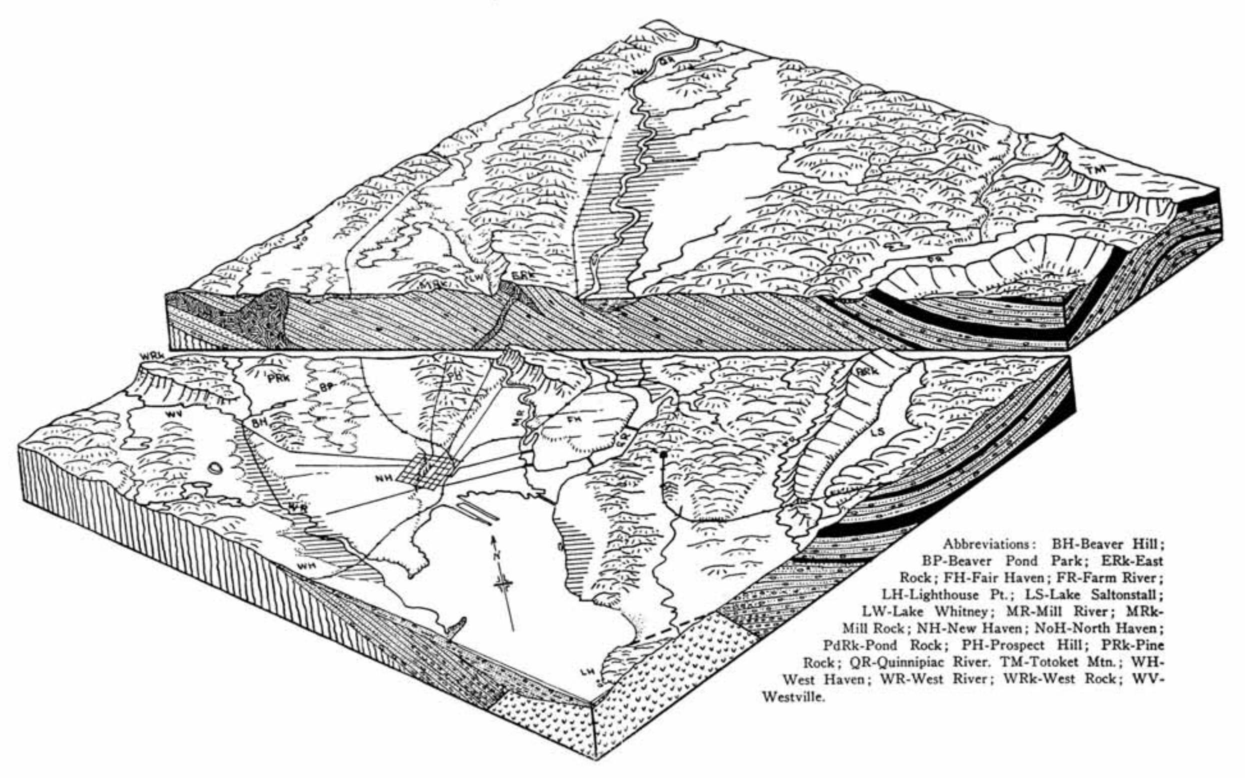


Figure 25 - Block diagram of New Haven area viewed obliquely downward from above with three sides cut away to show geologic structural relationships. Ridge-making extrusive igneous rocks shown in black (at right, in Branford); ridge-making intrusives shown by "ropy" line pattern (the two "rocks" in New Haven, West Rock at left; East Rock in center). (R. F. Flint, 1930, fig. 35, p. 178-179.)

[34.1] Crossing axis of deep buried valley.
[34.3] MP 46 on R; sign for upcoming Exit 46; move into L lane for upcoming left exit to I-91 northbound.
[34.4] Passing Exit 44 on R (CT Route 10, Kimberly Avenue).
[35.2] Passing Exit 46 on R (Long Wharf Drive and Sargeant Drive). New Haven harbor on R.
[35.8] Passing Exit 47 on L (CT Route 34, Downtown New Haven).
[35.9] Leave I-95; take Exit 48 on L to I-91 northbound toward Hartford.
[36.5] View ahead and to R: East Rock, a prominent landmark in New Haven, is underlain by resistant dolerite that forms a dike-sill pluton that intrudes the New Haven Arkose, the basal formation of the Newark Supergroup of the Hartford basin-filling strata. (See Table 3.)
[37.0] Passing Exit 3 on R (Trumbull Street, New Haven).
[37.4] Passing Exit 5 on R (US 5, State Street, Fair Haven).
[37.5] Passing on L, Exit 6 (Willow Street, Blatchley Avenue).
[37.9] Bridge over Quinnipiac River. The wide, marsh-capped lowland in which this river flows is somewhat comparable to the New Jersey Hackensack Meadowlands. The depth to bedrock beneath us is many hundreds of feet; how many is not well known. Neither the many old water wells nor the engineering borings for construction projects have been drilled deep enough to

reach the bedrock. (For the information on the valley fill where I-95 crosses the Quinnipiac River, see Upson, Leopold, and Rubin, 1964.)

[38.2] MP 2 on R.
[38.6] Passing pond on right where Upper Pleistocene varved clay (the New Haven Clay) that underlies the Holocene sediments has been removed for making bricks. Many such pits are present hereabouts. Antevs (1922, p. 226-227) found three overlapping series of varves amounting to 732 years. According to Schove (1984, p. 368), these lie in the period 16,500 to 15,500 b.p.

The Holocene sediments overlie the New Haven Clay along a surface of erosion; the thickness of the Holocene sediments reaches a maximum of about 20 feet (Figure 26). At the base is a gray sand, up to about 5 ft thick, probably deposited in an estuary by tidal currents (according to JES). Above that is a gray sandy silt, 2 to 3 ft thick, containing abundant fossil wood. The main body of the Holocene sediments consists of peat whose thickness reaches 15 feet (Bloom and Ellis, 1965, p. 2-3, figures 2 and 3). See also the section by R. W. Brown in Figure 21).

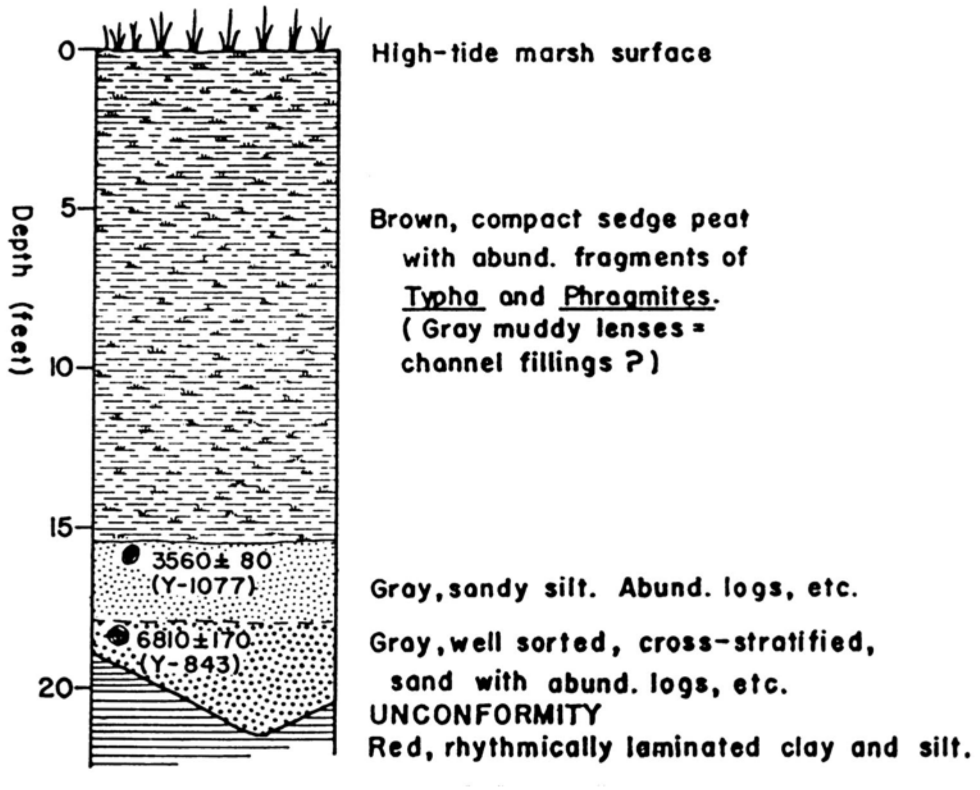


Figure 26 - Section through Holocene sediments exposed in Quinnipiac Valley, showing results of radiocarbon dating of fossil wood. (Bloom and Ellis, 1965, fig. 2, p. 2.)

[38.7] Passing Exit 8 on R (Middletown Avenue, CT Routes 17 and 80, to North Branford).
[38.9] On the L, Connecticut's Mount Trashmore, a rival (in current height, at least) to NYC's Fresh Kills operation on Staten Island).

[39.2] View ahead to Sleeping Giant, a group of hills whose profile when seen from the N or the S resembles a prone figure with head on the west (to the L as seen from here). The relief is formed by the resistance of the dolerite from an irregular pluton, as at East Rock. W. M. Davis (1898) imagined that the hills at Mount Carmel represented the eroded ramains of the neck of an ancient volcanic cone, as at Shiprock, New Mexico. Since 1898, geologists have not found any close connection between the pluton at Sleeping Giant and a volcanic cone.
[39.5] View to R of wooded ridge underlain by New Haven Arkose that has been intruded by a complex of dikes. The contact-metamorphosed arkose is more resistant to erosion that is the arkose that has not been affected by dikes. One of these dikes contains numerous "xenoliths" consisting of coarse, rounded quartz, evidently particles derived from a noncemented pebbly layer that the magma encountered on its ascent.

[39.7] Leave New Haven quadrnagle; enter Branford quadrangle.
[40.2] MP 4 on R.
[40.8] Passing Exit 9 on R (Montowese Avenue).
[41.0] Another view of Sleeping Giant on the L.
[41.3] MP 5 on R.
[41.5] Another pond formed by excavation on the R. But, at this pit, sand was excavated, not varved clay. The sand came from a delta that had been built into the proglacial lake in which the varved clays were accumulating.
[42.4] MP 6 on R.
[42.5] Passing Exit 10 on R (CT Route 40; Mt. Carmel, Hamden, Cheshire).
[42.8] Leave Branford quadrangle, enter Wallingford quadrangle.
[43.1] Passing ramp on R where northbound traffic enters from Exit 10.
[43.8] Passing Exit 11 on R (CT Route 22, North Haven).
[44.0] On bridge above AMTRAK RR tracks.
[44.5] MP 8 on R.
[44.9] Passing Exit 12 on R (US 5, Washington Avenue).
[45.5] MP 9 on R.
[46.1] Passing on L Exit 13 (US 5, Wallingford, North Haven, Wharton State Park). Exposed on R are strata of the New Haven Arkose, consisting of interbedded light-colored pebbly coarse arkoses and darker-colored red siltstones. The sandy layers are upward-fining cycles deposited in former shallow stream channels. The darker-colored silty layers represent former overbank deposits between the channels.

[46.6] MP 10 on R.
[47.6] MP 11 on R.
[48.2] Cuts display continous exposures of interbedded light-colored coarse layers and darker-colored finer strata of the New Haven Arkose dipping gently toward the northeast. The greenish spots are calcite-rich nodules marking ancient caliche soils. J. G. Percival (1842) noticed these. In the late 1950's JES spotted them as probable "fossil" caliches. The first published description of them and interpretation as caliche soils is in a paper by J. F. Hubert (1978).

[48.4] More of the same on R.
[48.5] Passing Exit 14 on R (CT Route 150, Woodhouse Avenue, Wallingford).
[48.6] MP 12.

[50.0-50.3] Pull-over stop. New Haven arkose with strata dipping gently toward the northeast in large cut in median. The coarse layers here display well-developed upward-fiing cycles typical of sediments deposited in a laterally migrating shallow stream channel.
[50.7] Passing under bridge for Rock Hill Road.
[50.8] MP 14 (Mileposts are off!).
[51.3] View ahead to small strike ridge known as Lamentation Mtn. and its smaller companion, Chauncey Peak. These two features are underlain by the NE-dipping Holyoke Formation, the thick middle unit of extrusives interlayered with the sedimentary strata filling the Hartford basin. (See Table 3.) Lamentation Mtn. and Chauncey Peak stand out in splendid isolation; they have been shifted from former positions that were part of a continuous outcrop belt of the Holyoke Formation.

JES raises the subject as to which of the Holyoke outcrop belts the Holyoke underlying Lamentation Mtn. and Chauncey Peak belongs. W. M. Davis (1882a, b; 1886, 1888, 1889a, b; 1898; Davis and Whittle, 1889) thought that at its N end, the Lamentation block had been faulted away from the E end of the Hanging Hills, Meriden, far to the L ahead (Figure 27). At the S end, Davis thought that Chauncey Peak had been faulted from Highby Mountain, the strike ridge forming the skyline close on our R. This interpretation made by Davis has been accepted by many others, including Longwell and Dana (1932), and most recently, by John Rodgers, author of the 1985 bedrock geologic map of Connecticut. By contrast, on the preliminary geologic map of Connecticut (Rodgers, Gates, and Rosenfeld, 1956), the fault was drawn as shown in Figure 18. JES thinks the 1956 map is more nearly correct than the 1985 map, but even the fault on the 1956 map needs revision. The JES view is shown in Figure 28.

JES argues that the Lamentation Mountain-Chauncey Peak segment is nothing more than a displaced piece of the Middletown syncline, as implied by Davis' map showing a NE-trending normal fault between Chauncey Peak and Higby Mtn. What JES vehemently objects to is a simple normal-fault connection between the N end of Lamentation Mountain and the Hanging Hills, Meriden. The basis for this objection is the JES assignment of the Hanging Hills to the Springfield syncline, which lies far to the N of the Middletown syncline and is separated from it by the Rocky Hill anticline, which is clearly shown by the curving outcrop belts of the Hampden Formation (the uppermost of the three extrusive complexes; Table 3). If the Hanging Hills do indeed belong to the Springfield syncline, as argued by JES, then the correct place to connect the E end of the Hanging Hills is somewhere north of the short Cedar Mountain strike ridge (underlain by the Holyoke Formation), which is about on the axis of the Rocky Hill anticline. JES infers that the fault between Lamentation Mountain and the Hanging Hills is not a simple NE-trending normal fault, but rather is the Hartford fault. According the the JES minority report (representing a population consisting of one), the Hartford fault trends nearly NS and is a strike-slip fault having about 20 km of L-lateral offset. JES sez: "All you have to do to interpret the structure correctly is to pay attention to the strikes and dips of the strata!"
[End digression - rejoin roadlog!]

[51.8] MP 15 on R.
[51.9] Redbeds and intercalated conglomerate.
[52.3] Passing Exit 15 on R (CT Route 68, Yalesville, Durham). View to north of strike ridges capped by sheets of resistant extrusive rock (= "trap rock).

[52.6] Passing beneath bridge for CT Route 68 overhead.
[52.8] MP 16 on R.
[53.4] More exposures of New Haven Akrose: redbeds and conglomerates.
[54.0] Leave Wallingford quadrangle; enter Meriden quadrangle.
[55.4] Passing Exit 16 on R (East Main Street; Ski Area).

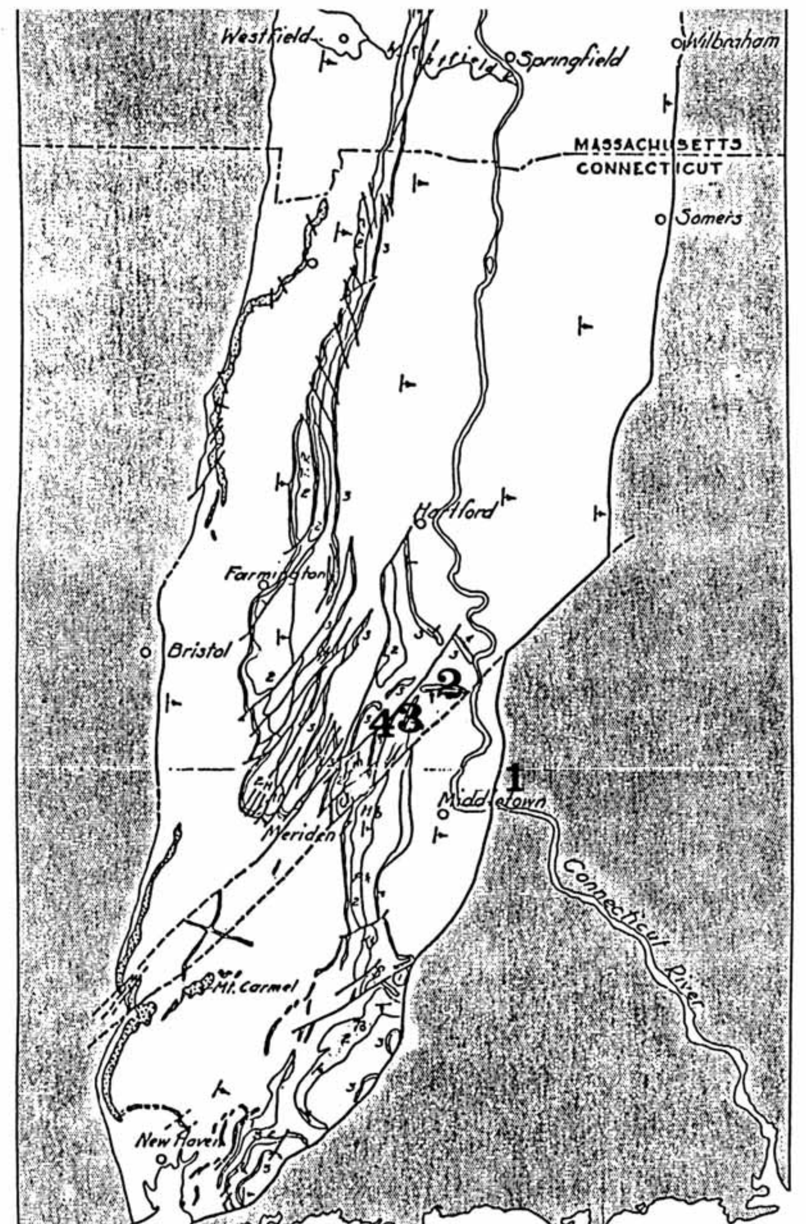


Figure 27 - Generalized geologic map of Hartford basin showing Lamentation fault block as first inferred by W. M. Davis in 1898. The Lamentation fault block is outlined by the two faults that pass through the label for the town of Meriden. (Longwell and Dana, 1932, plate I.) Our field-trip Stops 1 through 4 are shown.

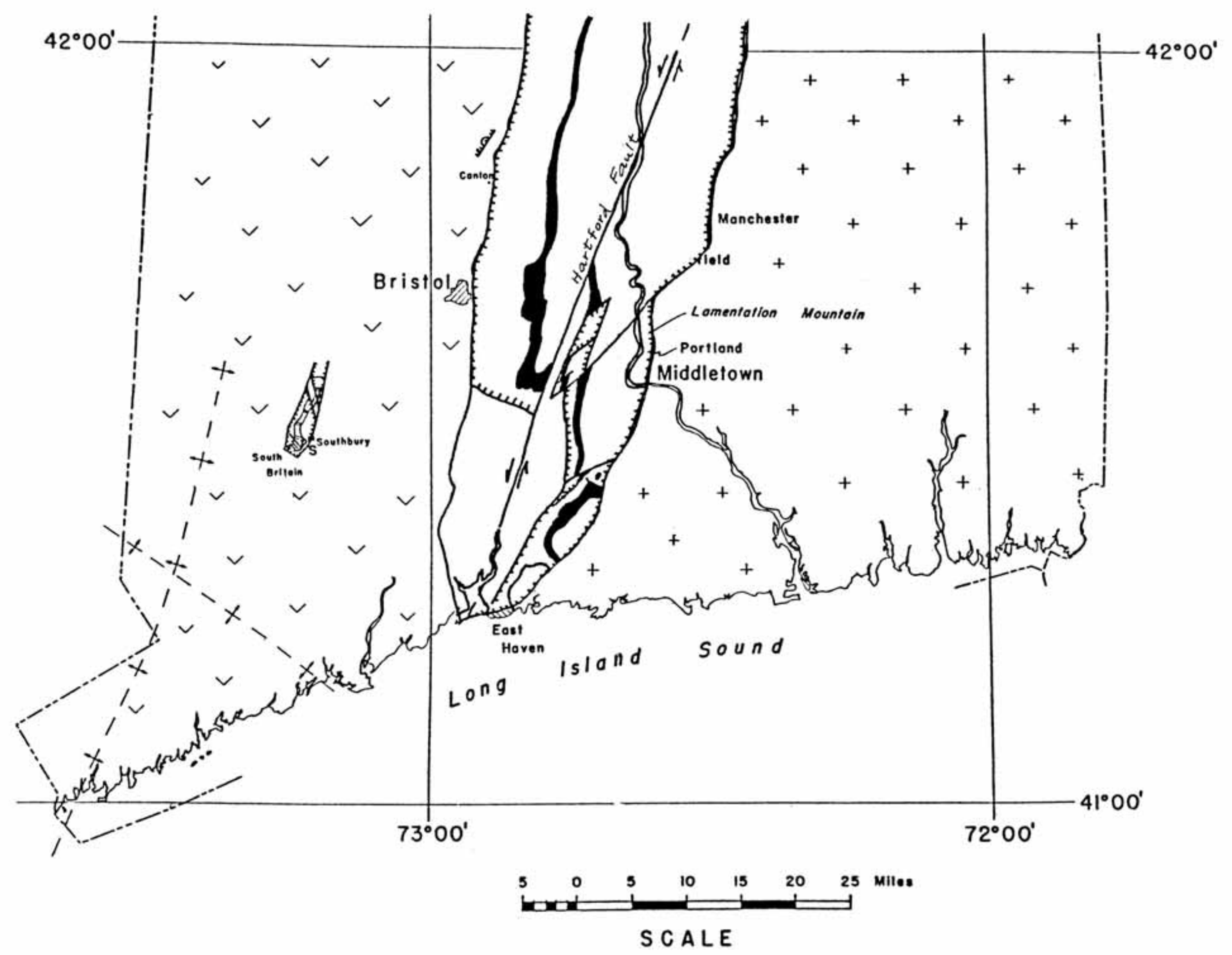


Figure 28 - Simplified tectonic map of the Hartford basin and Pomperaug basin, Connecticut. Outcrop of Holyoke Formation shown in black. Hartford fault shown as a left-lateral strike-slip fault having displacement of 13 mi. (J. E. Sanders.)

[55.5] MP 18 on R.
[56.2] Passing Exit 17 on R (CT Route 15 northbound,Berlin Tpk.; to CT Ret 66 eastbound; and I-691, formerly CT Route 66, westbound).
[56.7] Directly ahead are Lamentation Mtn. and Chauncey Peak; to far L are the Hanging Hills, Meriden.
[57.3] MP 20 on R (Passing Exit 18 (CT Route 66).
[57.5] View ahead to Higby Mtn., a strike ridge capped by the Holyoke Fm. The strata strike nearly NS and dip gently E as part of the Middletown syncline. Notice the extensive talus.
[58.1] Leave Meriden quadrangle; enter Middeltown quadrangle.
[58.3] Exposure on R of pillowed member of the Talcott Fm. (lowest extrusive complex) that has been smoothed and striated by a glacier. The breccia, pillows, and amygdales in the rock here are identical with those in the rock at the New Street quarry, Paterson, NJ, a locality well known to mineral collectors.

[58.8] Bear R to enter ramp to Tourist Info./Rest Stop. Enjoy a 15-minute break for stretching, pitting, and what not.
[59.0] Re-enter I-91 northbound.
[59.4] MP 22 on R.
[59.8] View ahead to the widest part of the Hartford basin. Most of the lowland in view is underlain by the Portland Formation, the uppermost formation of the Newark Supergroup (Table 3). From the Hanging Hills northward, the more-or-less continuous strike ridge underlain by the Holyoke Formation is situated close to the western margin of the outcrop belt. This arrangement contrasts with the situation in southern Connecticut, where we have been traveling so far. In southern Connecticut, the strike ridges underlain by the Holyoke Formation lie near the eastern margin of the outcrop belt, and the wide lowland to their west is underlain by the New Haven Arkose. At this point, we are about to cross from the southern arrangement (Holyoke ridges along the E margin of the outcrop belt) to the central arrangement (Holyoke ridges along the W margin of the outcrop belt). Just ahead on the L are Chauncey Peak-Lamentation Mtn., where the strata strike about NS and dip gently to the E. In the distance to the L is the dip slope on the top of the Holyoke Formation that underlies the Hanging Hills, Meriden. In the Hanging Hills, the strata strike NW-SE and dip NE.

[60.2] On the R, more talus from the Holyoke Formation underlying Higby Mtn.
[61.0] More glaciated trap rock on R.
[61.5] MP 24 on R.
[62.0] Red sedimentary strata exposed on R. What is the correct formational assignment of these? Is it to the Portland Formation (youngest unit)? Or to the East Berlin Formation (sedimentary unit between the Holyoke and Hampden extrusives)? The 1985 Connecticut geologic map shows Portland. JES concurs.
[62.6] MP 25 on R.
[63.4] Leave I-91 via ramp on R at Exit 21 (CT Route 372 to Cromwell and Berlin).
[63.7] At end of ramp, turn L (toward Cromwell).
[64.1] Passing RJ with East Street. The river on our R is the Mettabessett.
[64.3] On L, exposure of Hampden Basalt (upper extrusive complex).
[64.8] Passing local street.
[65.05] Passing RJ with CT Route 3.
[65.1] Turn R to enter ramp for CT Route 9 southbound.
[65.3] On CT Route 9 southbound (toward Middletown).
[65.8] Start big curve to L.
[66.2] End curve.
[66.6] Start big curve to R.
[67.1] End curve to R; ahead is Connecticut River.
[67.3] Passing ramp on R for traffic entering from CT Route 99. Keep to R for upcoming R turn at traffic light.
[68.4] Traffic signal; turn R for CT Route 66, 17A (to Middletown and the Arrigoni Bridge over the Connecticut River to Portland).
[68.7] At top of hill, enter traffic circle; keep R for CT Route 66 eastbound and CT Route 17A northbound].
[69.1] On Arrigoni Bridge over the meandering Connecticut River. Look R and L for spectacular views to the north and south along the river valley. On the north side of the eastern

footing of the bridge, are large sandstone quarries, the type locality for the Portland Formation. Here, the hematite-stained arkose and quartzose sandstones have been quarried for use as building stones. Some of the older buildings in Portland (ahead) are constructed of these materials. New Yorkers know this appealing but easily friable building material as "brownstone". Just downstream from this bridge, the river curves to its L and leaves the Central Valley province to enter the Eastern Uplands province. The boundary between these two provinces is the basin-marginal fault at the east side of the Hartford basin.

[69.4] Above E shore of the Connecticut River; move into L lane to avoid the R-turn traffic at the next light.
[68.8] At first traffic light on E side of river, go straight following Conn. Route 17A through Portland.
[70.3] US Post Office on L. Note the architectural style of the buildings in Portland and the extensive use of red sandstone ("Connecticut brownstone").
[71.3] Bartlett Street Extension on R and statue composed of red-brown Portland Sandstone. Leave Middletown quadrangle, enter Middle Haddam quadrangle. Continue ahead on CT Route 17A.
[72.1] Here, CT Route 17A has descended to the edge of the meandering Connecticut River where it still flows within the Central Valley. To the L is Gildersleeve Island. Flooding is common along this stretch of 17A and the Bartlett Street Extension links with Routes 17 and 17A for just such an emergency.
[72.7] Junction with CT Route 17 (Glastonbury Turnpike; the local name for this intersection is Fogelmarks Corners). Go straight across on CT Route 17A.
[72.8] Turn L into Cornwall Street.
[73.1] At T-intersection and stop sign, turn L into Old Marlborough Turnpike. Straight ahead is the famous Strickland Hill with the Strickland quarries to our south (R).
[74.0] Just after powerline crossing, turn L into Thompson Hill Road.
[74.3] Powerline crossing again.
[74.6] Turn R into Cotton Hill Road.
[74.7] Under the powerlines, pull over to the L and park for STOP 1.

STOP 1 - Case Quarries. [UTM Coordinates: 701.4E / 4610.2N, Middle Haddam quadrangle.]

The Case quarries were owned by Myron N. Case of Rose Hill, Portland Connecticut according to Cameron and others (1954). From 1933 to 1935, the Worth Spar Company, Inc., of Cobalt, Connecticut, quarried the three pegmatites for feldspar. The quarries were last worked in 1942. The workings are open cuts that range from 20 to 40 meters in length, 2 to 15 meters in width, and 3 to 8 meters in depth. They were mapped in 1943 by E. N. Cameron and V. E. Schairer and their map is here reproduced as Figure 29.

The three pegmatites of the Case quarry lie within 160 m of one another. They strike north to northeast with variable dip (Figure 29) and cross cut their host rock, the Monson Gneiss that strikes northward and dips west at 20° to 30°. The border zone of No. 1 pegmatite is 1 to 3 cm thick and consists of granular quartz, plagioclase, perthite, and beryl. The remainder of the pegmatite consists of perthite and quartz, with subordinate plagioclase and muscovite, and accessory beryl, garnet, and columbite-tantalite. Beryl occurs chiefly in the border zone and in the outermost 30 to 45 cm of the perthite-quartz zone. Crystals range from 0.5 to 10 cm in length and up to 7.5 cm in diameter.

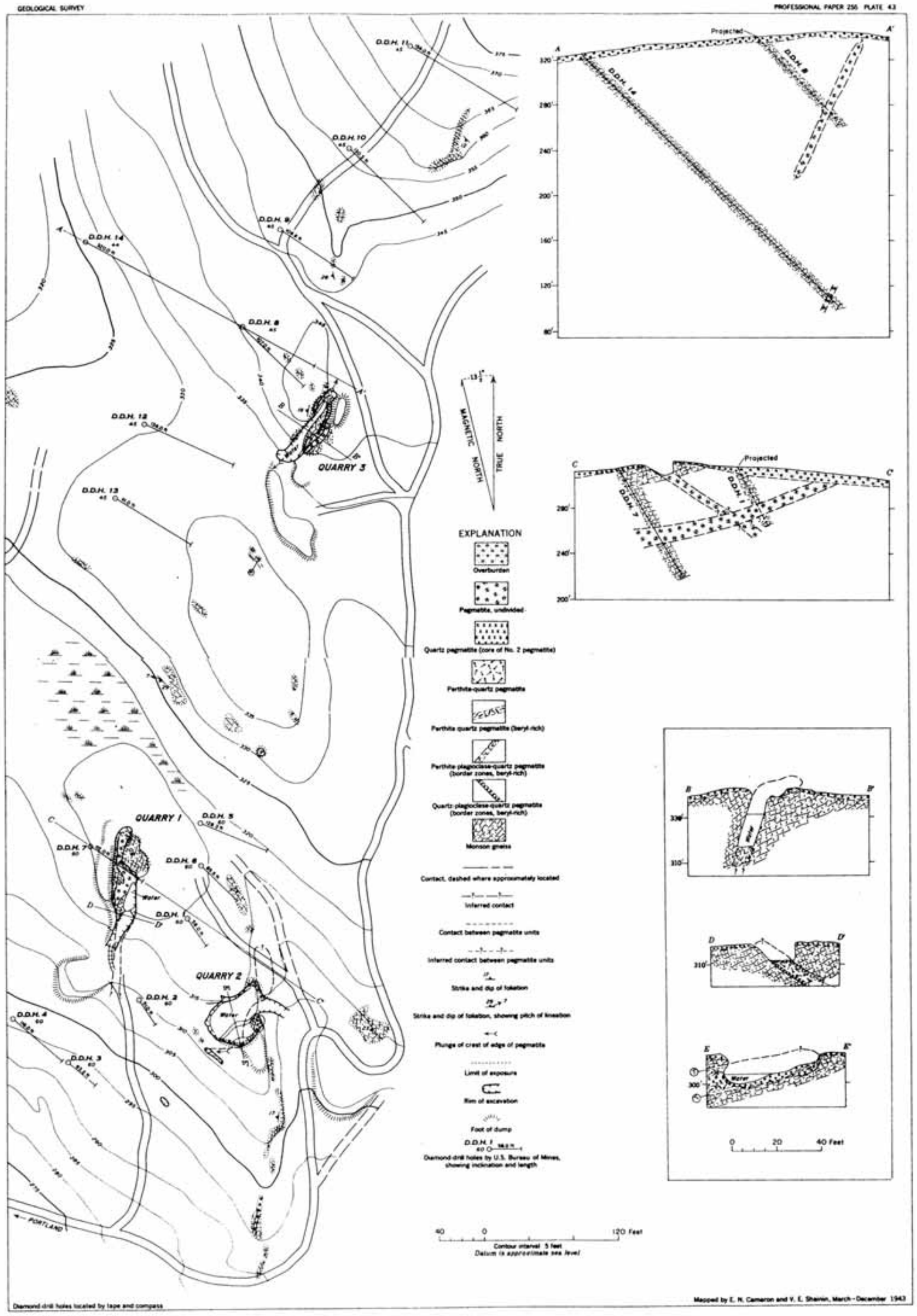


Figure 29 - Topography, geologic map, locations of diamond-drill holes, and profile-sections of the Case beryl prospects, Portland, Connecticut. (Cameron and others, 1943.)

The No. 2 pegmatite is a tabular lens that strikes N17°E and dips 15° NW with a strike length of 20 m. It is distinctly zoned with a border zone consisting of fine-textured quartz, perthite, and plagioclase, with accessory muscovite, garnet, beryl, and tourmaline. The wall zone is 5 to 15 cm thick and consists of medium-textured perthite, plagioclase, and quartz, with accessory muscovite, beryl and garnet. The thickness of the core zone averages 2 m; it is composed of crystalline milky quartz and accessory perthite in scattered large, euhedral crystals and rare beryl. An intermediate zone, 0.4 to 1.3 m thick, separates the core zone from the wall zone and consists of quartz and coarse-textured perthite. Beryl is present in the border- and wall zones in scattered crystals 0.6 to 2 cm in diameter and as much as 8 cm long. The largest crystal is reported to have been 22.5 cm in diameter and 25 cm long.

The No. 3 pegmatite is a tabular lens that strikes N25° to 48°E and dips roughly 65° NW. It exhibits a distinct zonal structure. A border zone, 1.25 to 2.5 cm thick, is composed of quartz, perthite, and plagioclase, with accessory black tourmaline, muscovite, beryl, and garnet. The wall zone is 0.3 to 0.7 m thick, but locally pinches out, and consists of quartz and plagioclase with variable amounts of perthite, subordinate muscovite, accessory beryl, tourmaline, and columbite-tantalite. The core is irregular but locally consists of quartz and perthite. Beryl occurs in the border zone in crystals less than 0.6 cm in diameter and 2.5 cm long, and in the wall zone crystals are 5 cm in diameter and up to 12.5 cm long.

According to estimates by Cameron and others (1954), the Case No. 2 and 3 quarries contained slightly more than 100 tons of beryl, mostly in small crystals. Much of this material was left by the Worth Spar Company in mine dumps around the area. So, get comfortable and begin scratching around and most importantly, down, for some nice specimens of beryl, tourmaline, and columbite-tantalite. Other minerals found here, but not mentioned above, include: albite, almandite, autunite, biotite, bismite, bismuthinite, bismutite, chalcopyrite, cyrtolite, epidote, fluorapatite, goethite, hornblende, limonite, microcline, muscovite, opal, pyrite, pyrolusite, spessartite, torbernite, uraninite, and uranophane according to Januzzi (1972).

During a visit by CM in April of 1984, bluish beryl crystals were observed in Case Quarry No. 3 grown in quartz, perpendicular to the contact between the Monson Gneiss and adjacent quartz vein. Pickings were scarce during a CM field trip in July of 1990 but the "Connecticut quarry fairies" may have restocked the tailings pile since. In the mine-dump area, the best matrix-specimen beryl occurs in the feldspathic pegmatite material. Uranium minerals are found in association with smoky quartz. Happy hunting.

[74.7] Retrace route back to Arrigoni Bridge; start by turning around and heading back on Cotton Hill Road.
[75.0] Turn L on Thompson Hill Rd.
[75.2] Powerline crossing.
[75.5] At STOP sign, turn R into Marlborough Turnpike.
[75.8] Glacial erratics on L and R.
[76.4] At STOP sign, turn R into Cornwall Street.
[76.7] At STOP sign, turn R. Note Pleistocene gravel pit to L.
[76.8] At STOP sign and red blinking light, go straight ahead into CT Route 17A.

[78.2] Junction with Bartlett Street Extension on L. Leave Middle Haddam quadrangle, re-enter Middletown quadrangle.
[79.2] Traffic light at Post Office.
[79.5] Traffic light at RJ where CT Routes 17 and 66 enter from L. Continue straight ahead toward bridge. On bridge, notice Wilcox Island to the R and turnable RR bridge to L. After road curves to the L, follow the signs to Conn. Route 9 .
[80,4] At traffic light, turn L towards CT Route 9.
[80.6] RJ with CT Route9; turn L and follow CT Route 9 North along the west bank of the Connecticut River.
[81.5] Leave CT Route 9 at Exit 18; bear R for CT Route 99 north to Cromwell and Rocky Hill.
[82.1] Yellow blinking light at South Street.
[82.3] RR crossing.
[82.4] Fabulous downtown Cromwell near intersection with West Street.
[83.6] Passing Evergreen Road on L.
[84.0] Passing Court Street on L.
[84.4] Leave Middletown quadrangle, enter Hartford South quadrangle.
[85.1] Enter Rocky Hill.
[85.7] Passing Brook Street on L.
[85.8] Traffic light at Gorman Road. Continue straight ahead on CT Route 99 northbound.[
[86.3] At traffic light (and Texaco station), turn L into West Street; follow signs for I-91.
[87.0] Entrance to Dinosaur State Park on L; turn L into Park.
[87.1] Park vans in lot. Get out. Stretch. Pit stop. LUNCH in picnic area ahead. After lunch, STOP 2.

STOP 2 - Dinosaur State Park at Rocky Hill. [UTM Coordinates: 695.3E / 4613.6N, Hartford South quadrangle.]

The following account of the history of Dinosaur State Park is quoted from Rodgers and Skinner (1985, Trip C1, Stop 8, p. C1-10 and C1-ll).:

"In 1966, the State Highway Department chose this site for a central Highway Department Research Laboratory, close to but not on Interstate I-91 near the geographic center of the state. One Friday afternoon in August (JES note: according to Ostrom, 1968, p. C3-1, the date was 24 August 1966), one of the bull-dozer (sic) operators, Mr. Ed McCarthy, engaged in clearing the overburden to bedrock before construction, turned up flat slabs of sandstone on which he recognized some large dinosaur footprints (such prints have of course been well known in the Connecticut Valley for 150 years). After investigating, the project engineer, Mr. Tom Jeffreys, stopped excavation in the area and called the Yale Peabody Museum, the University of Connecticut, and the newspapers; later an announcement was broadcast on TV, and the Saturday Hartford Courant carried the story. As word of the find spread, many persons came down over the weekend to pick up samples for their patios, rock-gardens, etc. The news also reached Ms. Jane Cheney, Director of the Children's Museum in Hartford, who went directly to Governor John Dempsey (about to stand for re-election) and persuaded him that the find was exceptional and should be preserved. At a meeting of state officials on Monday morning, it was agreed that the Peabody Museum would direct the bull-dozer operators while they determined the size and significance of the deposit; Prof. John Ostrom of the Museum and Prof. Joe Webb Peoples of Wesleyan University, then Director of the Connecticut Geological and Natural History Survey, were in general charge. Later the Governor declared the locality The Dinosaur State Park. A news item concerning the dinosaur trackway appeared on the front page of the Hartford Courant for twelve straight days. Clearing continued for several weeks, until a single surface of sandstone displayed over (sic) two thousand tracks. Testing elsewhere on the property showed that the layer with the tracks was even more extensive; moreover it is only one of five layers within about 2 meters of rock that display tracks.

"By this time, it was thought that enough had been uncovered to make a spectacular display, and the work was stopped; the main concern after that was to preserve the tracks against the approaching winter's freezes and thaws. The tracks were therefore covered up, and, except for one or two brief spells, the main discovery site has not been uncovered since. On the other hand (sic), in 1967 a more modest (sic) area was uncovered west of the main site (in the same layers), which could be covered by a temporary structure (a plastic bubble kept up by excess air pressure), and this area became the main exhibit at the Park. Later the temporary structure was replaced by the present more permanent (sic) structure, but the original plan to build a larger museum over the main, original discovery has never been carried through. In any case, the Park was duly dedicated in 1967 by Governor Dempsey; honor was paid to Mr. McCarthy, the original finder of the tracks; and the Rocky Hill High School Band played a new piece of music called 'Dinosaur', written for the occasion by its director.

"As the Hampden flow forms the ridge immediately south of the trackway area, the stratigraphic position is known exactly; when the I-91 cuts about 2 1/2 miles to the southwest were opened, the trackway levels were pinpointed there. While the main trackway was still uncovered, a trench was dug down dip to the south, which showed that the trackway layers are cut downdip by a small thrust fault, dipping south more steeply than the beds, so that the trackways (sic) layers are brought back up closer to the land surface. If a museum is ever built over the original site, this trench could be reopened and the thrust fault displayed. Its westward extension is clearly responsible for the right offset of the Hampden ridge between the Park and I-91.

"The Highway Department, deprived of their orignal site, had to recommece operations about a mile farther east, and rumor has it that the bulldozer operators were given strict order to stop for nothing. (P. S. Ed McCarthy, the bulldozer operator-dinosaur-footprint-discoverer, became a local folk hero. He had been "educated" about dinosaur footprints by his daughter, then in grade school, who had become fascinated by what she had learned about dinosaurs at school. What he saw were counterparts of the original footprints, made as depressions in the underlying mud but now preserved as positive-relief features on the bottoms of the overlying sandstone layers. Few, if any, footprints are present on the tops of the sandstones. Subsequently, Mr. McCarthy was reassigned to "other duties;" his supervisors evidently figuring that his rate of bulldozing would drop dramatically because he probably would be studying every piece of sandstone his blade turned over.)

During the Jurassic Period, roughly 185 Ma, mudflats extended over much of the flat floor of the Hartford basin. Fault-related uplifts along the eastern basin-marginal fault of this basin provided intermittent supplies of coarse clastic sediments eroded from the pre-Triassic crystalline rocks of the persistently elevated Eastern Highland block. Into the Hartford basin poured many sediments that we now see as interbedded red sandstones, shales, conglomerates and non-red-colored lacustrine deposits. Many dinosaurs traversed these muddy plains searching for food (not mineral specimens as had been commonly thought!) and left tracks in their wake (Figure 30; See also Figure 5). Fossil bones of these dinosaurs have never been found as the conditions that preserve tracks are not the best for preserving bone, but the search continues. The geodesic dome constructed here preserves a multitude of tracks for the public to see and admire. We will stop here for lunch and, time permitting a brief visit to the dinosaur footprint area where you may create a plaster cast of a Eubrontes footprint. Unfortunately the dinosaur trackway exhibit is under construction at present (06/94) and we will not be allowed access to this area (site of Jurassic dinosaur strolls).

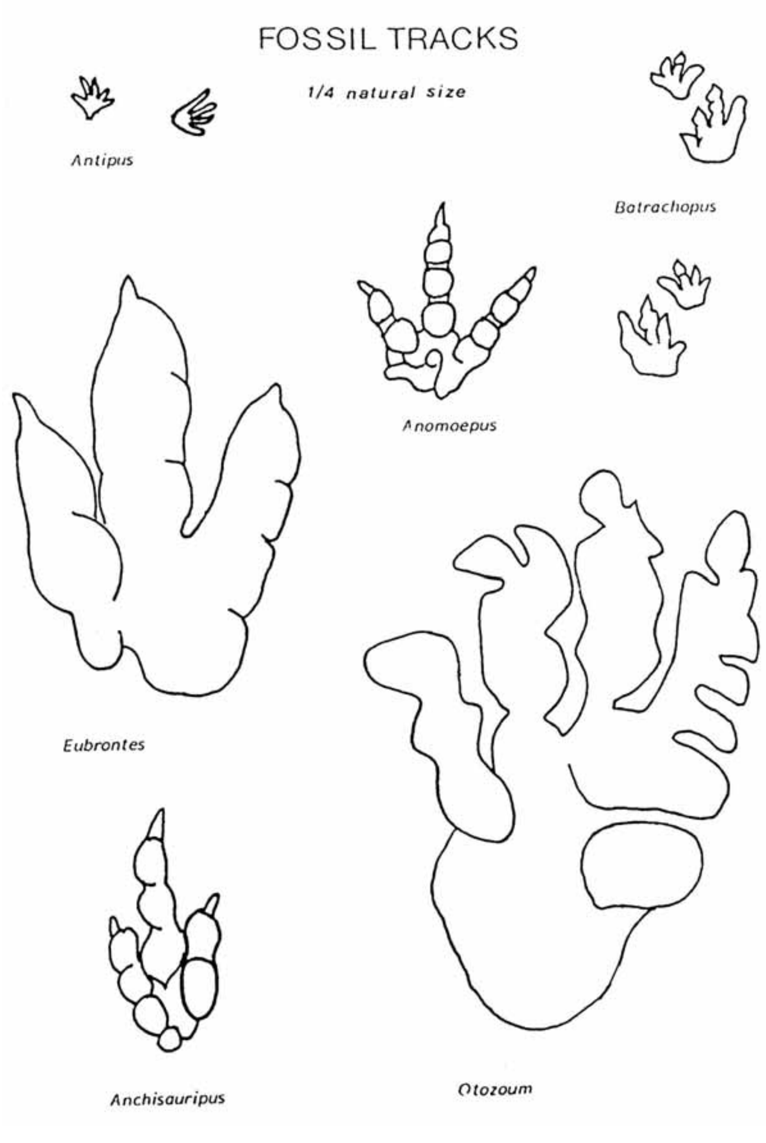


Figure 30 - Sketches of various dinosaur footprints. (Guidebook to Dinosaur State Park, published by Friends of Dinosaur State Park, 1988, p. 23.)

[87.1] Reboard vans and head out of parking area.
[87.2] Turn L into West Street.
[87.5] Passing Gilbert Avenue on R.
[87.8] Traffic light; on L, glaciated surface of Hampden Basalt. At Dinosaur Park, the footprints were in the East Berlin Formation, which underlies the Hampden. The Hampden capped the wooded knoll to the S. Between here and the Park, we have crossed a fault that throws the Hampden down on the west to bring it alongside West Street.

[87.9] Traffic light at road junction with I-91 Northbound. Go straight ahead on West Street passing over I-91.
[88.1] At traffic light, turn L for I-91 southbound.
[88.3] On I-91 southbound.
[88.5] MP 29 on R.
[89.5] MP 30 on R.
[89.8] Leave I-91; bear R to enter ramp for Exit 22N (to CT Route 9 N), in an area formerly known by the locals as "Texas" (that was after these cuts had been excavated, but no pavement had been laid down, and the area was left to grow wild). Cromwell Town line; also, leave Hartford Co., enter New Haven Co.
[90.1] Start cuts on R, in Hampden Basalt (uppermost extrusive).
[90.2] Pull over to R for Stop 3. Upper part of East Berlin Formation and contact with overlying Hampden Basalt.

STOP 3 - Hampden Basalt and East Berlin Formation, Cromwell. [UTM Coordinates: 692.0E / 4610.8N, Hartford South quadrangle.]

G. deV. Klein (1968); Hubert, Reed, and Carey, 1976; Hubert, Reed, Dowdall, and Gilchrist (1978); P. E. Olsen (1984 ms.) have published descriptions of the East Berlin formation exposed here during the "Texas" time period. All of these authors have emphasized the cyclicity of these sediments, which were deposited in lakes of varying water depth and along the margins of lakes. Figure 31 shows the typical lake cycle according to Hubert and others (1978). The most-comprehensive interpretation of these Newark ancient lake deposits in terms of changing water levels has been presented by P. E. Olsen (1986) for the Lockatong Formation in New Jersey. Olsen has set forth the details of what he named a Van Houten cycle, that is the sediments deposited during a change from a deep-water lake (typical deposit, a black shale) to a shallow-water lake (red mudstone) to an alluvial plain (sandstone) and back again to a deep-water lake. Olsen's chronologic reconstruction connects these changes in level of the Mesozoic lakes with periods that are the same as those calculated by Milankovitch for the Pleistocene changes of climate associated with astronomic factors that cause the Earth's orbit and axial tilt to change.

One thing we would particularly like to do here is see if we can find the layers that contain the dinosaur trackways seen at Stop 2. Other things to notice are the conditions associated with the contact between the basalt and the sedimentary layers. Notice the chilled margin in the basalt and the effects of the heat from the lava on the underlying sedimentary strata.

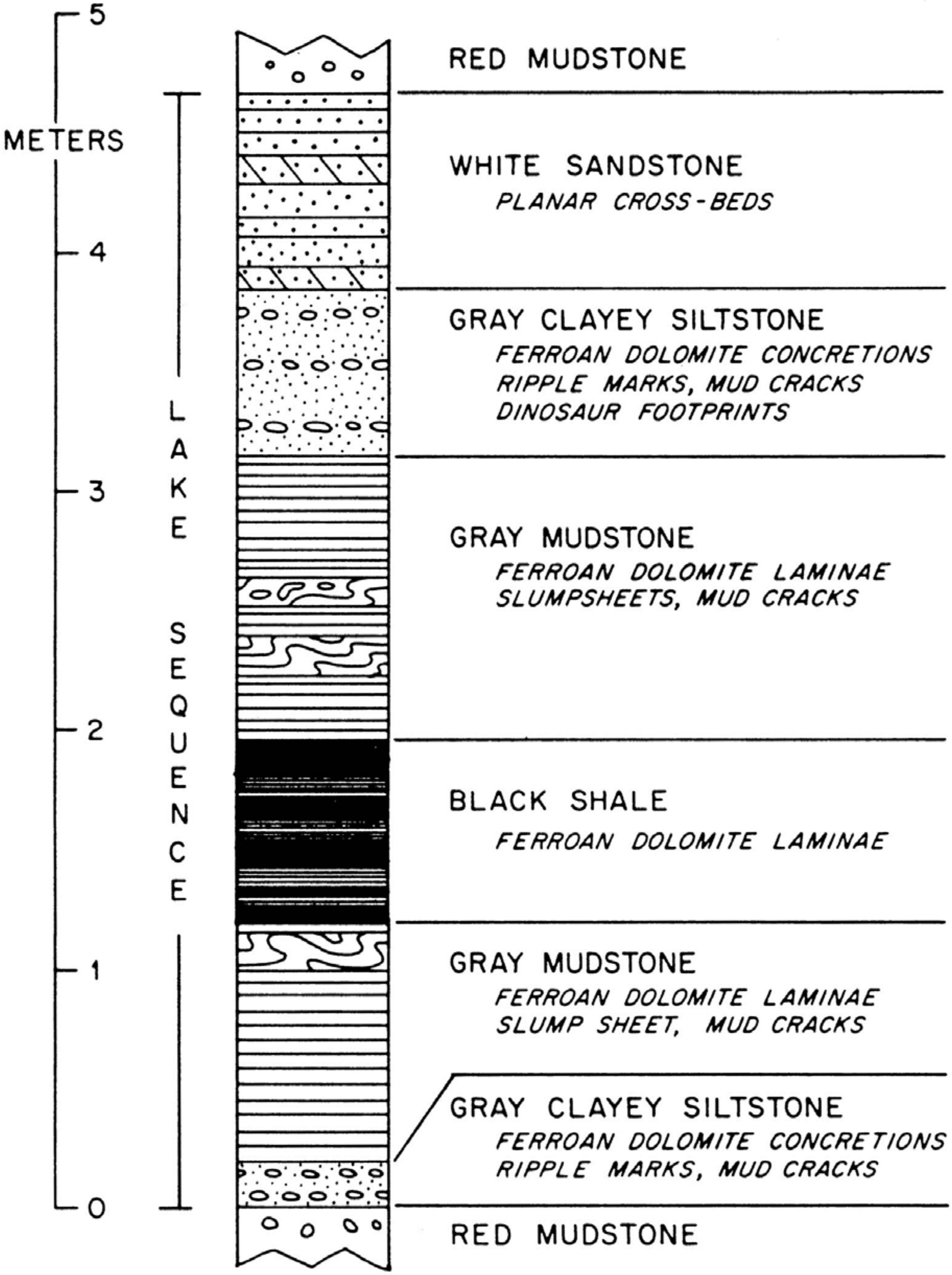


Figure 31 - Generalized cyclic arrangement of lake deposits in East Berlin Formation, Cromwell, CT (our Stop 3). (McDonald, 1985, after Hubert and others, 1978.)

[90.2] Reboard vans and continue on CT Route 9 northbound.
[90.5] End of continuous exposure.
[90.7] MP 30 on R.; crossing covered interval. Ahead is a dip slope on the Hampden Basalt on the E side of a strike ridge. We are probably crossing the fault on which the strata ahead of us have been dropped down on the west and thus repeated. If one extended the dip of the contact seen at Stop 3 up into the air using the same dip as in the road cut, then the contact here would be about 1000 feet above our heads.
[91.3] Crossing creek.
[91.7] MP 31 on R.
[92.1] Leave CT Route 9 at Exit 21; bear R for CT Route 372 to East Berlin.
[92.4] At end of ramp, turn R..
[92.5] Exposure of Hampden Basalt W of the fault the drops the Hampden-East Berlin formations downward and thus repeats them.
[92.6] Pull over in driveway to R for Stop 4.

STOP 4 - Hampden Basalt and East Berlin Formation, East Berlin. [UTM Coordinates: 688.5E/ 4610.2N, Middletown quadrangle.]

Exposed here are the upper layers of the East Berlin Formation (this is the type locality so designated by E. P. Lehmann in 1959) and contact with overlying Hampden Basalt (the same units as at Stop 3, but repeated here by being relatively downdropped about 2000 feet on a normal fault). Some large and splendid glacial grooves are visible at top of knoll on NE side of the road (a larger surface now available than shown in the photograph of Fig. 13.15, p. 319 in Sanders, 1981).

Lehmann's measured section if the East Berlin Formation is shown graphically in Figure 32, which also includes George deVries Klein's interpretation of a typical cycle. The lower part of the Hampden Basalt contains bent-over pipestem vesicles that indicate the direction of flow of the lava before final cooling. We will use a compass to record the direction implied. Notice the "vesicles" in the underlying siltstone!

[92.6] Reboard vans; continue NW on CT Route 372.
[92.8] Traffic light; ramp for US 5 and CT Route 15 northbound; leave Middletown quadrangle, re-enter Hartford South quadrangle.
Move into L lane for upcoming L turn.
[93.0] Traffic light; turn L for US 5 and CT Route 15 southbound. Go under road; keep to L. Re-enter Middletown quadrangle.
[93.05] Turn L for road to New Haven; view ahead to new cuts in the East Berlin Formation along ramp leading to CT Route 9. Notice the cyclic repetition of the strata, particularly of the black shales (the deep-water lake deposits).
[93.3] Entering US 5-CT Route 15 southbound (Berlin Turnpike).
[93.8] Traffic light.
[94.1] View ahead to Lamentation Mtn. (now seen from the N); the Berlin Turnpike more or less follows the trace of JES' Hartford Fault.
[94.4] Leave Middletown quadrangle; re-enter Meriden quadrangle.

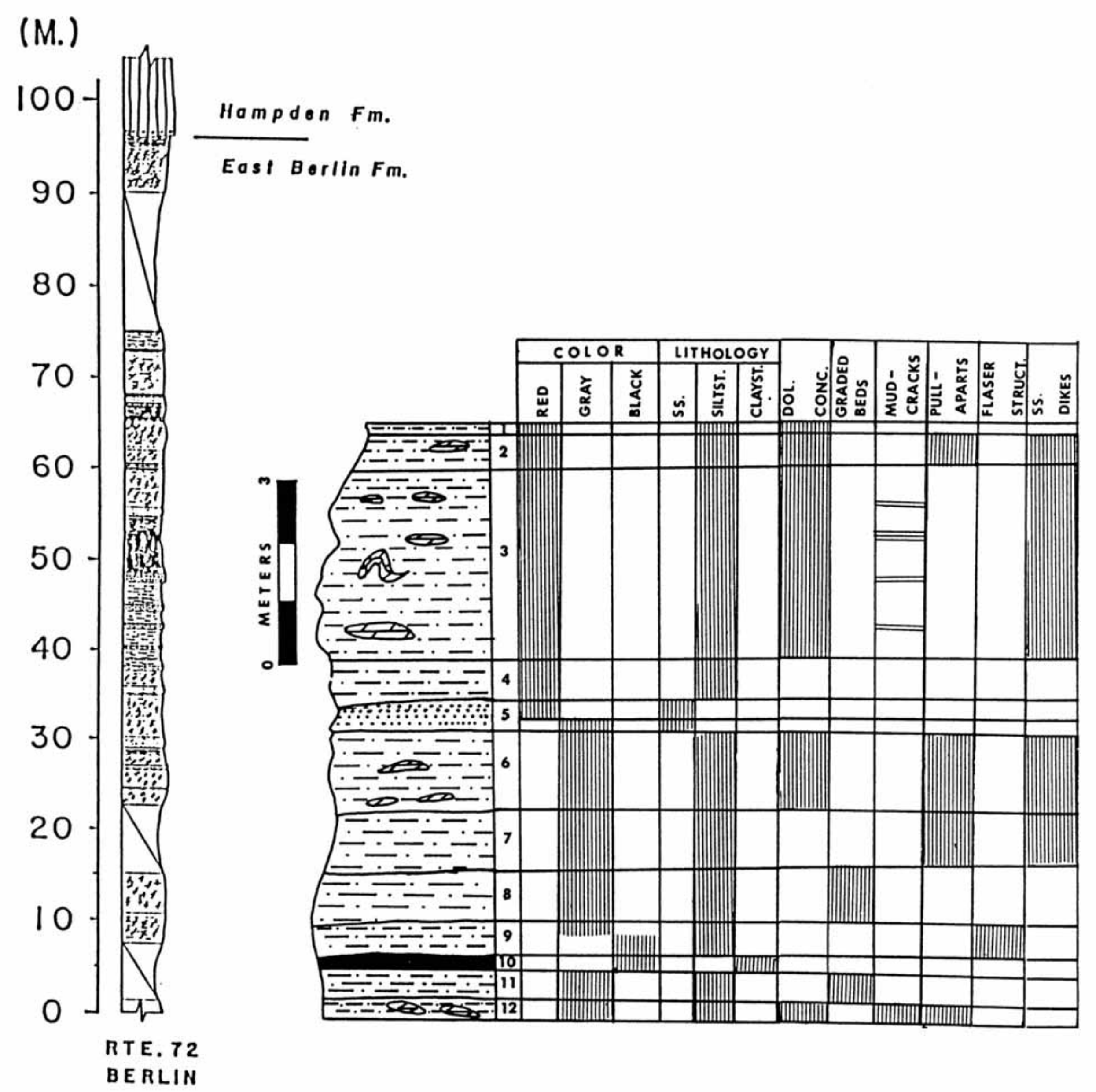


Figure 32 - East Berlin Formation at type locality, cuts on CT Route 372, East Berlin (our Stop 4).

A. Columnar section as measured by E. P. Lehmann and drawn by J. E. Sanders (1965, fig. 5, p. 277).

B. Idealized cycle in mixed facies of East Berlin Formation as represented by G. deV. Klein (1968, fig. 4, p. C1-10).

[94.5] Traffic light.
[95.1] Traffic light. Spruce Brook Road on L.
[95.3] Traffic light. Orchard Road on R. View ahead to Lamentation Mtn.
[95.5] Traffic light.

[96.1] Mt. Royal Motel on L; patrons get to sleep on pillowed basalt (at no extra charge!)
[96.2] Exposure on L of pillowed Talcott Formation.
[96.3] Traffic light (Toll Gate Road).
[96.8] Traffic light (North Colony Road on R; opposite E shore of Silver Lake).
[97.1] Important landmark on L (CT office of OTG); in the cut behind the building one can see the contact between basalt (above) and sandstone (below). If this is the lowermost of the Talcott basalt members, then this is the contact between the base of the Talcott Formation and the top of the New Haven Arkose. If the basalt is not the lowermost member of the Talcott Formation, then the contact is between one of the basalt members of the Talcott and one of the sedimentary members.

[97.3] Traffic light.
[98.1] Passing on the R the ramp to US 5; curve L.
[99.6] Passing beneath bridge for I-691 above (former CT Route 66).
[100.1] Passing Exit 67 W on R; move L to join I-19 southbound.
[102.4] Leave Meriden quad., re-enter Wallingford quad.
[102.6] MP 17 on R.
[103.7] Passing Exit 15 on R (CT Route 68 to Durham, Yalesville).
[104.7] MP 15 on R.
[105.2] Bear R to enter ramp for entrance to Rest Area & Tourist Info. PIT stop - 15 minutes.

[105.2] Re-board vans and continue south on I-91.
[105.8] MP 14 on R where ramp from rest area rejoins I-91 S.
[106.3] Large cut on R; New Haven Arkose.
[106.5] End of cuts.
[106.6] Passing Exit 14 (CT Route 150, E. Center St., Wallingford).
[106.9] MP 13 on R.
[107.9] MP 12 by ramp entering on R (S-bound from Exit 14).
[108.1] Start large cuts in New Haven Arkose (coarse layers here are non-soRouted products of debris flows in contrast with coarser layers we have seen elsewhere that are products of shallow stream channels).
[108.4] End of large cuts.
[108.9] MP 11 on R.
[109.1] Passing Exit 13 on R (US 5, Wallingford).
[109.5] North Haven Town Line.
[110.0] MP 10 on R.
[111.0] MP 9 on R.
[111.4] Passing Exit 12 on R (Washington Ave., North Haven).
[111.8] Crossing over AMTRAK RR tracks; Quinnipiac River.
[112.1] MP 8 on R.
[113.3] Pond on R; former sand pit in proglacial-lake delta.
[113.5] Passing Exit 10 on R (CT Route 40, Mt. Carmel, Hamden).
[113.8] Leave Wallingford quad., re-enter Branford quadrangle.

[END OF DETAILED ROAD LOG]

[115.8] Passing Exit 9 ramp on R. Wooded knoll on L is Rabbit Rock, underlain by a dolerite sill.
[116.6] Leave Branford quad., re-enter New Haven quad.
[117.3] On R, CT Mt. Trashmore landfill (A.K.A. North Haven Town Dump.)
[117.4] Passing Exit 8 ramp on R.
[117.8] Bridge over AMTRAK RR; view of East Rock on R, with tall monument on top.
[118.7] Passing Exit 6 on R. View ahead to downtown New Haven. Move into center lane for I-15 southbound (to NY City).
[119.9] Passing Exit 2 ramp on R.
[120.1] Take ramp for I-95 southbound (to NY City).

[END OF END OF ROAD LOG]

ACKNOWLEDGEMENTS

We would like to thank the usual roundup of assistants in our On-The-Rocks field trip endeavors including the staff of Duke Geological Laboratory, and Matt Katz, and Executive Assistant Marcie Brenner of the New York Academy of Sciences. We also wish to thank Ms. Brenda Sauer for taking the time to reschedule events to accommodate our group at Rocky Hill.

The field-trip leaders (CM and JES) wish to thank all of our field-trip participants, present and past, for their unbridled enthusiasm for our thirty-one consecutive geologic field trips (especially those where the weather was bleak!). This field-trip guidebook is dedicated to Mr. Earle C. Sullivan of Trumbull, Mr. John Carter of Winsted, and to the late Mr. Ray Wadhams formerly of Torrington, (three of the "Good Old Boys") who took the time to introduce CM to Connecticut humor as well as to many, many mineral collecting sites and places of geologic and culinary interest.

We look forward to seeing our veteran On-The-Rockers and new proto-Rockers next season (Fall 1994) when we plan to repeat our two-day trip to the Little Appalachians and the Catskills (September 24-25) and a trip to Staten Island (Sunday, October 16) in conjunction with the annual meeting of the Geological Association of New Jersey. Until then, just keep on rockin'-- ;)

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.
(Triassic)	190	Continued filling of subsiding Newark basins and mafic igneous activity both extrusive and intrusive. Newark basins form and fill with non-marine sediments.

PALEOZOIC 245

(Permian)		Pre-Newark erosion surface formed.
	260	**Appalachian orogeny.** (Terminal stage.) Folding, overthrusting, and metamorphism of Rhode Island coal basins; granites intruded.
(Carboniferous)		Faulting, folding, and metamorphism in New York City area. Southeastern New York undergoes continued uplift and erosion.
(Devonian)	365	**Acadian orogeny.** Deep burial of sedimentary strata. Faulting, folding, and metamorphism in New York City area. Peekskill Granite and Acadian granites intruded.
(Silurian)		
	440	**Taconic orogeny.** Intense deformation and metamorphism.
	450	Cortlandt Complex and related rocks intrude Taconian suture zone. (Cameron's Line). 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 - Generalized Descriptions of Major Geologic "Layers", SE New York State and Vicinity

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

LAYER VII - QUATERNARY SEDIMENTS

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

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

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

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

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

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

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

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

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

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

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

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

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

LAYER IV - COAL MEASURES AND RELATED STRATA (Carboniferous)

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

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

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

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

marine)	(graded layers, marine)
Bakoven Black Shale	Cornwall Black Shale
Onondaga Limestone	
Schoharie buff siltstone	Pine Hill Formation
Esopus Formation	Esopus Formation
Glenerie Chert	
Connelly Conglomerate	Connelly Conglomerate
Central Valley Sandstone	
Carbonates of Helderberg Group	Carbonates of Helderberg Group
Manlius Limestone	
Rondout Formation	Rondout Formation
Decker Formation	
Binnewater Sandstone	Poxono Island Formation
High Falls Shale	Longwood Red Shale
Shawangunk Formation	Green Pond Conglomerate

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

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

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

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

Not metamorphosed / Metamorphosed
Martinsburg Fm. / Manhattan Schist (Om - lower unit).
Normanskill Fm. / Annsville Phyllite

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

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

LAYER IIA[W] - SAUK SEQUENCE

Western shallow-water
platform (L. Cambrian-
M. Ordovician)

Copake Limestone
Rochdale Limestone
Halcyon Lake Fm.
Briarcliff Dolostone
Pine Plains Fm.
Stissing Dolostone
Poughquag Quartzite
Lowerre Quartzite [Base not known]

LAYER IIA[E] - TACONIC SEQUENCE

Eastern deep-water zone
(L. Cambrian-M. Ordovician)

Stockbridge
or Inwood Marbles

(Є-Oh) Hartland Fm.
(Є-Om) Manhattan Fm.
(in part).

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

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

LAYER I - PROTEROZOIC BASEMENT ROCKS

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

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

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

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

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

Table 03 - 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 04 – 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).
Illinoian(?)	IIIA	NW to SE	Ronkonkoma Terminal Moraine and associated outwash (Merrick Fm. in Jones Beach subsurface).
	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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