DUKE GEOLOGICAL LABORATORY

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TRIPS ON THE ROCKS

Guide 19: Delaware River Valley Transect of the Newark Basin, New Jersey

Trip 27: 19 June 1993

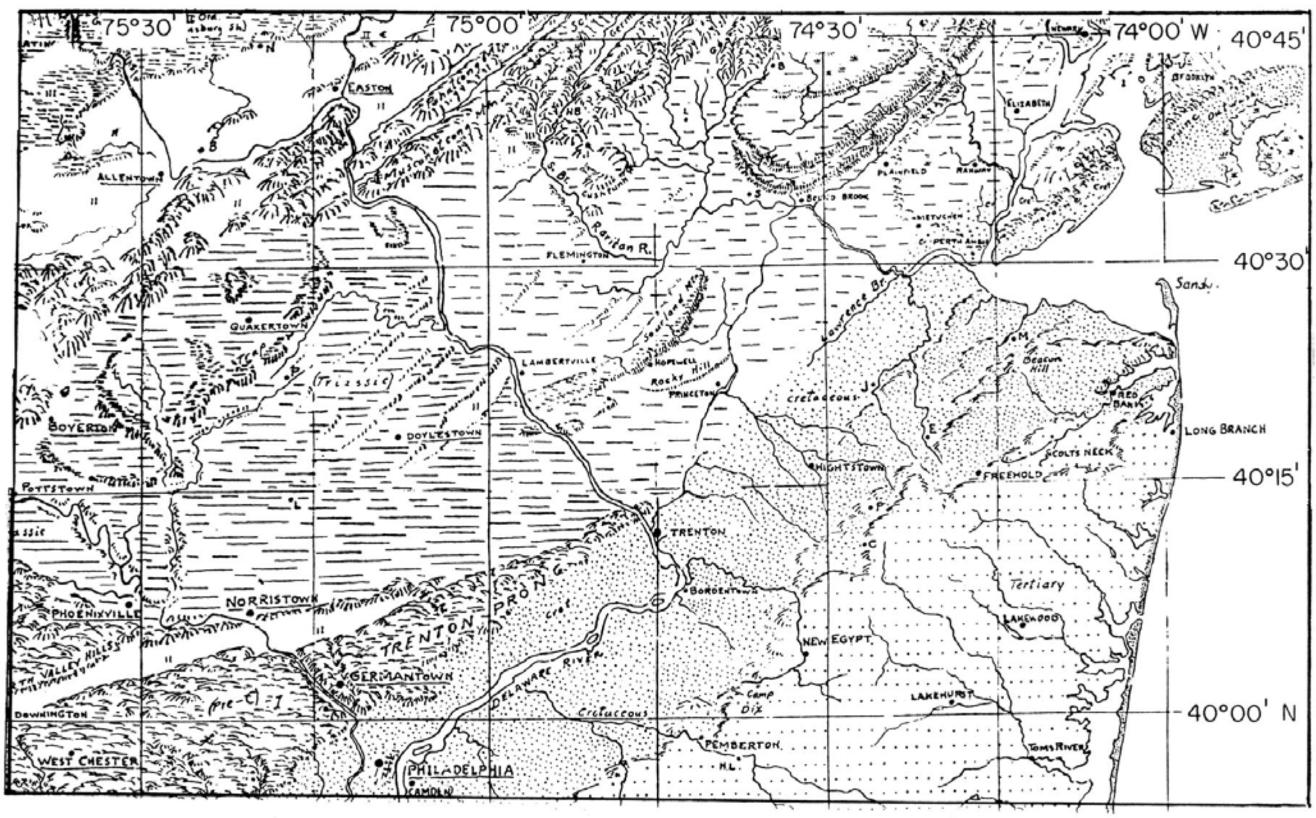

Figure 1. Physiographic block diagram of central New Jersey and eastern Pennsylvania showing the southern part of the Newark Basin and the Delaware River Valley. (Drawing by A. K. Lobeck, Columbia University.)

Field Trip Notes by:

Charles Merguerian and John E. Sanders

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Guide 19: Delaware River Valley Transect of the Newark Basin, New Jersey

Trip 27: 19 June 1993

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

INTRODUCTION

Today's trip in the Delaware River valley of central New Jersey (Figure 1, cover) across the strata filling the Newark basin will demonstrate the great geologic contrasts with the Newark basin-filling strata in northern New Jersey where the Watchung extrusive sheets form prominent topographic ridges that dominate the landscape, where no one section exposes more than a few tens of meters of strata, and where glacial sediments form a nearly continuous surficial blanket. In the Delaware River valley segment we shall examine today, only a few igneous intrusive rocks but no extrusives are present; the landscape is dominated by deeply incised rivers; and the territory lies outside the southern limit of the Pleistocene glacial advances.

The splendid exposures in the Delaware River valley of eastern Pennsylvania and west-central New Jersey have been key localities that many generations of geologists have studied and from their studies, have expressed various contrasting ideas. Early in the nineteenth century, the Delaware River valley exposures prompted the Rogers brothers to begin their much-repeated series of denials that the Newark strata could be anywhere as thick as one would suppose from making a traverse along the Delaware River from Trenton northwestward for an across-strike distance of nearly 50 km (31 mi) and computing stratigraphic thickness using an average dip of 12° and applying simple trigonometric functions (50 x sin 12°, which is 0.2079, or 10.4 km). When the pre-Newark rocks of Buckingham Mountain opposite Stockton, NJ were identified, the overall thickness could be reduced in half because of repetition by a large fault (subsequently named in New Jersey the Flemington fault). Still, the resulting value of 5 km was more than the Rogers brothers could accept.

After the Newark had been subdivided into Stockton, Lockatong, and Brunswick formations (Kümmel 1899a), another fault repetition was discovered: the upper part of the Stockton Formation and overlying Lockatong beds that underlie Sourland Mountain had been displaced upward against some part of the Brunswick Formation (Figure 2). This second fault was named the Hopewell fault. Both the Flemington fault and the Hopewell fault were classified as normal faults; that is, the displacements on them were more or less parallel to the dip of the fault surfaces.

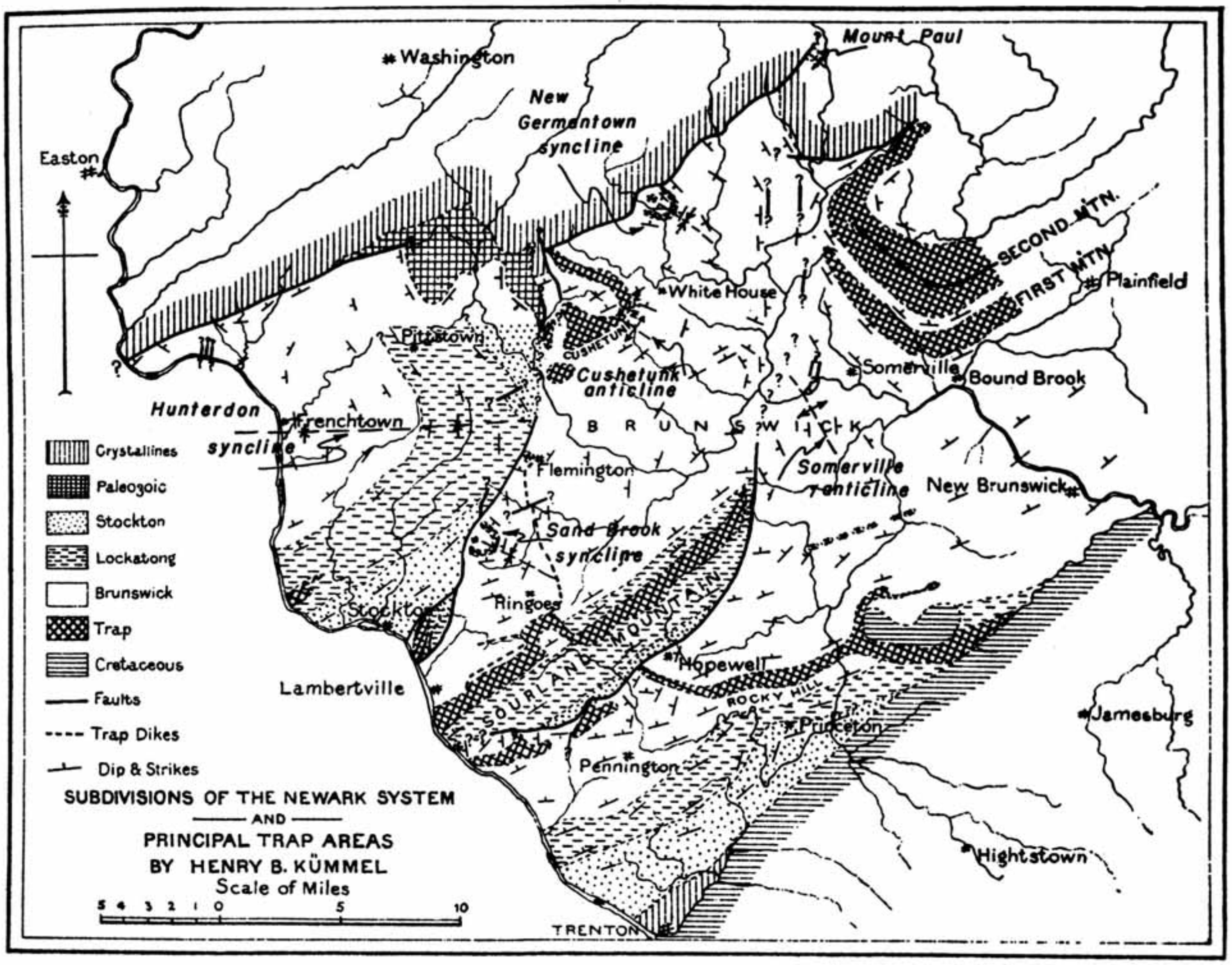

Figure 2. Geologic map of the southwestern part of the New Jersey Triassic belt [after Kümmel (1897), with names of folds given by Wheeler (1937), and location of Mount Paul added by J. E. Sanders]. (Sanders, 1962, Figure 1, p. 41.)

The geologic public did not gag over the recognition of these large normal faults. First of all, normal faults are the expected kinds of faults present in regions subjected to tensional forces. Second, these faults, as large as they are, were welcomed because they lowered by at least 50% the amount of inescapable stratigraphic thickness that had to be believed. But folds were to prove something altogether different.

N. H. Darton (1889, 1890) first recognized the folds in central New Jersey. A few other geologists paid attention to the folds, but most geologists treated these folds like sleeping dogs; they let them lie undisturbed. Most of the discussion about folded Newark strata came from central Connecticut, where the W. M. Davis (1882a,b; 1883, 1886, 1888, 1898) and students proved that the sheets of mafic igneous rock are extrusives and thus can be used for structural mapping. In central Connecticut, the folds in Newark strata are so obvious that they cannot be overlooked. C. R. Longwell (1922, 1928, 1933) even showed that the folds had been offset by post-fold faults.

But, obvious or not, folds by definition imply that awful "C" word, compression. The geologists studying the Newark were under the spell of the "T" word; the Newark episode was widely believed to be a product of tension. The "C" word was supposed to characterize the Late Paleozoic Appalachian deformation. Thereafter, "C" was thought to have been supplanted by the big "T." Where "T" prevails, no folds are supposed to be present; folds, please go away. Even when Girard Wheeler (1939) published a scheme by which folds could form as byproducts of tensional-fault movements, the geologic public refused to dilute its adherence to the "T" religion by admitting any kind of "C" heresy.

JES entered into the debate about the structural relationships of the Newark strata via the Longwell route, pursuing CRL's point that folds had been offset by faults. In so doing, JES stirred up another "forbidden" subject: strike-slip faults. Simple regional tension and strike-slip faults are not exactly compatible geologic "bedfellows." (But, as has been said of politicians, they may make strange bedfellows, but they soon become accustomed to the same old bunk!) Indeed, when George Bain (1941) first suggested that strike-slip faults are present at the northeast end of the Holyoke Range, central Massachusetts, he was scorned. It does not require much imagination to visualize that the JES (1962) claim of strike-slip faults, based as it was on the displacement of vertical axial planes of folds, was not destined to release a pent-up stampede of enthusiasm. How much credence do you suppose was attached to an argument that depended on the offsetting of fold axes when few geologists would even deign to admit that any folds are present? JES's 1962 paper was greeted by massive yawning or brushed aside without comment as "speculation" (Van Houten, 1969, p. 328).

One of the chief objectives of today's trip is to examine some new roadcut exposures that display the rocks in one of these fault zones (the Dilts Corner fault, which is associated with the Flemington fault). The section on geologic background will give you the various points of view that have been expressed. But, most of all, participants will be able to see for themselves.

One of the major lessons to be learned from today's trip is that new exposures can be the basis for completely different interpretations of geologic relationships that have been accepted for many years without question. We will see what comes from a few roadcuts. Imagine all the fabulous new things that will be appearing soon as a result of the core-drilling program carried out in the Newark basin at the Lamont-Doherty Earth Observatory of Columbia University under the direction of Dennis Kent and Paul Olsen. From these cores, a complete record of the strata filling the Newark basin will be available. A tangible record in these cores will supplant numerous "covered intervals" that have been accepted previously as part of the "givens" in studying the Newark basin.

GEOLOGIC BACKGROUND

We begin this section with a general discussion of the major bedrock units including Layers I and II, V, and VI. (See Tables 1 and 2.) Under the heading "Layer V: The Newark Basin-Filling Strata", we discuss the strata and structures of the south part of the Newark Basin as exposed in the vicinity of the Delaware River.

BEDROCK UNITS

The central focus of today's trip is the Newark Supergroup, which we list collectively in Table 2 as Layer V. The Newark Supergroup is a thick sequence of Upper Triassic to Lower Jurassic (Mesozoic) sedimentary strata and interbedded sheets of mafic volcanic rocks whose basal part was intruded by a thick body of mafic magma that cooled to form intrusive igneous rock of the Palisades Sill. The Newark Supergroup rests with profound angular unconformity atop folded and faulted units of Layers I and II, the pre-Newark complex of Paleozoic and older metamorphic rocks that underlies the Manhattan Prong of the New England Uplands. Rocks of Layer I crop out immediately west of the Ramapo fault zone. Here, they underlie the Ramapo Mountains, a tract of hilly, highly glaciated crystalline rocks whose lithologic units trend northeast-southwest parallel to that of the range.

These rocks lie along strike and are continuous with correlative rocks of the Hudson Highlands examined on our NYAS On-The-Rocks Trips Nos. 2 and 14. And, as we saw on the trip to Staten Island (On-The-Rocks Trips Nos. 4 and 19), the tilted and eroded edges of the Newark strata were overlapped and covered by the strata of Layer VI, the coastal-plain strata. Although we will not study the coastal-plain strata on today's trip, we mention them because they are products of a totally contrasting geologic setting from the Newark basin-filling strata, and their position above the tilted and eroded Newark strata places a definitive upper limit on the time of the deformation of the Newark strata (pre-Late Cretaceous by an amount of time sufficient to enable the Newark strata to have been deformed and trucated by erosion). We review these layers in general terms, starting with the oldest and progressing to the youngest.

Layers I and II: Pre-Newark Complex of Paleozoic and Older Rocks

Before we begin our geological journey from the New York Academy of Sciences, a few thoughts about the rocks beneath our feet. The crystalline bedrock of New York City marks the southern terminus of an important sequence of metamorphosed Precambrian- to Lower Paleozoic rocks of the Manhattan Prong (Figure 3) which widens northward into the New England Upland physiographic province.

The oldest rocks of the Manhattan Prong do not crop out in Manhattan. These oldest rocks consist of a sequence of layered feldspathic- and massive granitoid gneiss, amphibolite, and calc-silicate rocks of uncertain stratigraphic relationships known as the Fordham and Yonkers gneisses (Layer I). These formations were complexly deformed during the Grenville Orogeny roughly 1.1 Billion years ago. This complexly deformed basement sequence of Layer I represents the ancient continental crust of proto-North America.

Proterozoic rocks of the Reading Prong occur to the northwest of the Ramapo Fault in west-central New Jersey. Extending southwestward from their correlatives forming the Hudson Highlands, allochthonous rocks of the Reading Prong consist of the layered sequences of the Losee Metamorphic Suite and of interlayered calcareous- and quartzofeldspathic gneisses. They also include intrusive rocks of the Byram Intrusive Suite and pyroxene granites and related quartz-poor rocks. Older Proterozoic sequences have been identified by many workers but will not be included here.

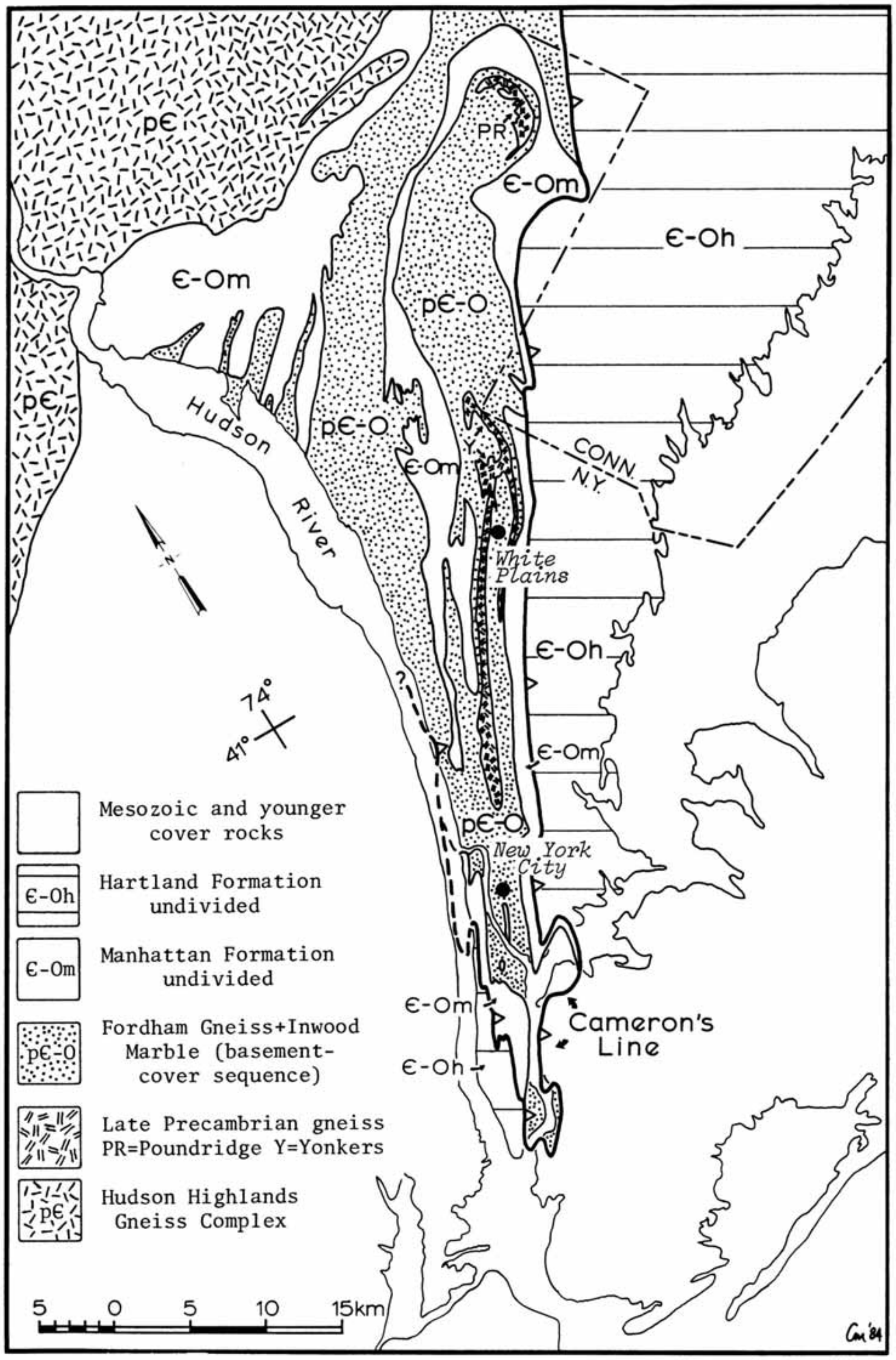

Figure 3. Simplified geologic map of Manhattan Prong showing the distribution of metamorphic rocks ranging in ages from Precambrian to Early Paleozoic. Most intrusive rocks have been omitted. (Mose and Merguerian, 1985).

The sequence has experienced at least one high-grade Proterozoic metamorphism and two episodes of low-grade Paleozoic metamorphic recrystallization. Folding and thrust faulting during dynamothermal metamorphism has resulted in an imbricate stack of thrust sheets wherein Paleozoic cover rocks are locally preserved.

In New York City, the Paleozoic bedrock units (Layer II) now form a deeply eroded sequence of highly metamorphosed, folded and faulted sedimentary- and igneous rocks (Figure 4). After the older Proterozoic basement complex had been exposed, eroded, and subsided the Paleozoic units were deposited above it. This pre-Paleozoic erosion surface marks a gap in the geologic record known as an unconformity that has been encountered in numerous borings and has been mapped by Hall (1968a,b) in White Plains, New York, and vicinity.

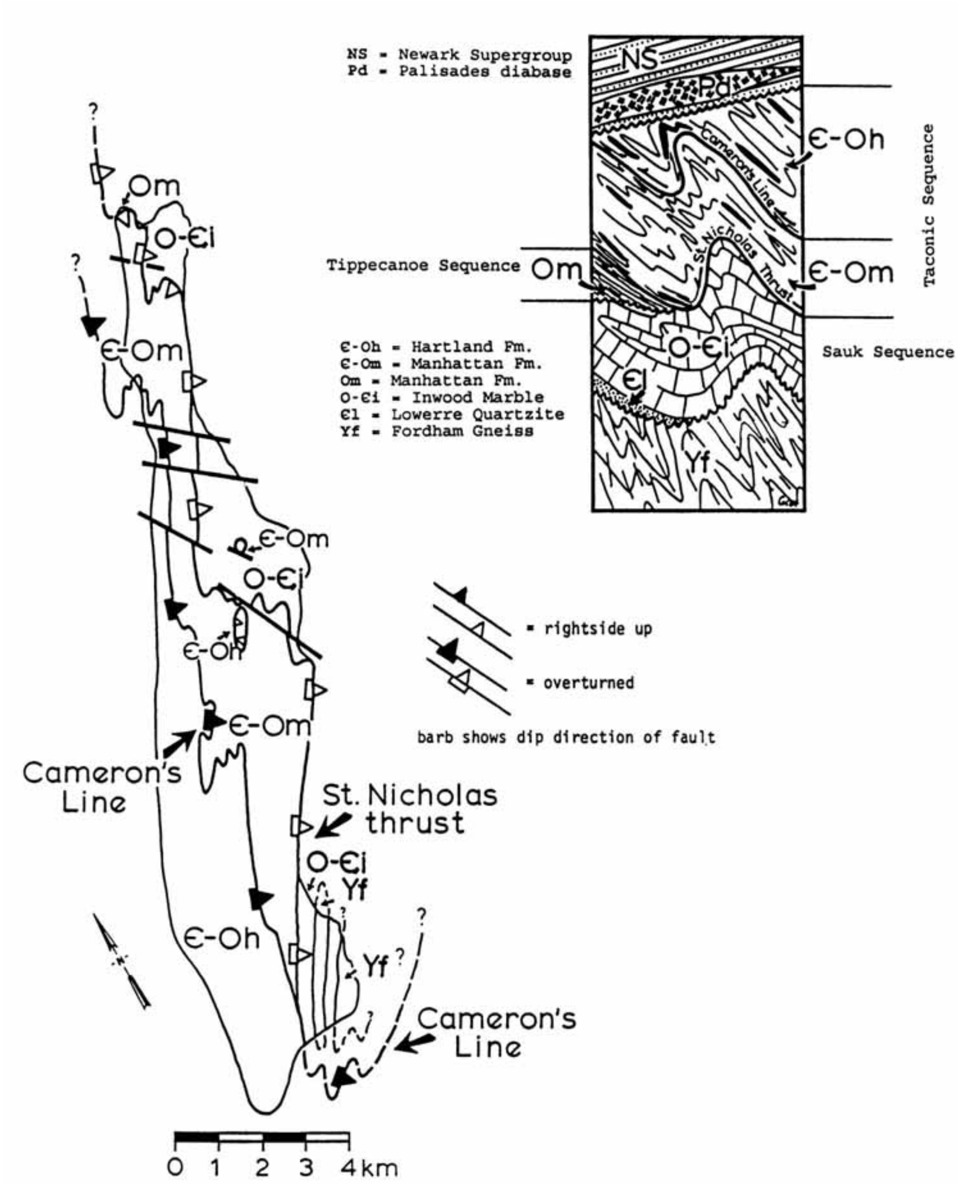

Figure 4. Geologic map and section of Manhattan. (C. Merguerian, unpublished data.)

The formations of Layer II were deposited as thick accumulations of both shallow- and deep-water sediments adjacent to the Early Paleozoic shoreline of proto-North America roughly 500 million years ago. 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. Layer IIA can be split into two facies that differ in composition as a function of their original geographic positions with respect to the shoreline and shelf. A nearshore/shelf facies [Layer IIA(W)] was deposited in shallow water and is now represented by Cambrian clastics and Cambro-Ordovician carbonates (originally sandy and limey sediments, respectively; it is the eastern part of the Sauk Sequence of Sloss, 1963).

During a series of Paleozoic mountain-building episodes (the Taconic-, Acadian-, and terminal-Appalachian orogenies), the sedimentary protoliths of Layer II were folded and metamorphosed into the lower Cambrian quartzite (Poughquag, Lowerre, Hardyston, Chickies, and Setters), Cambro-Ordovician dolomitic- and calcite marble (Stockbridge, Wappinger, Inwood, and Kittatinny), and middle Ordovician pelitic phyllite and schist (Annsville, Manhattan [in part], and Wissahickon [in part]). Here, the term schist(s) is intentionally plural to indicate that the Manhattan and Wissahickon formations are composed of ductile-fault-bounded units that were imbricated during the Paleozoic orogeny.

A NW-SE geologic section across the central part of the Newark Basin is shown in Figure 5. Note that the Proterozoic- and younger Paleozoic basement-cover rocks are strongly deformed by imbricate thrusts and large-scale folds which locally preserve Paleozoic strata. The basement-cover squence is unconformably overlain by the Newark Supergroup. The unconformity surface projects out of the Hudson River over Manhattan in New York City. Along strike toward the southwest is covered by coastal-plain strata of Layer VI. The unconformity surface reappears in the vicinity of Trenton, New Jersey and continues southwestward as the northwestward limit of the Piedmont.

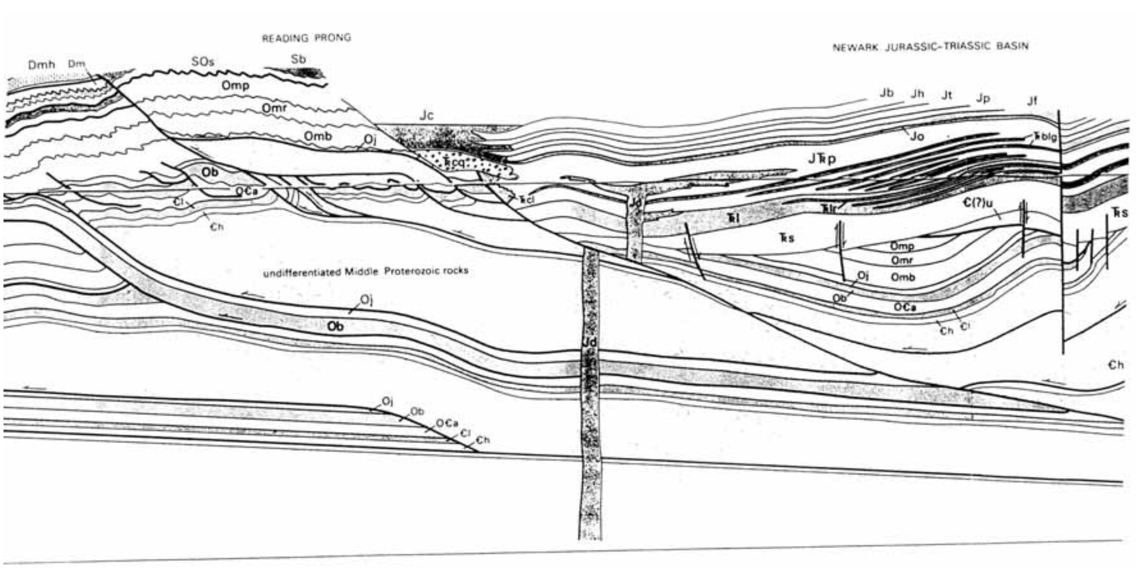

Figure 5. NNW-SSE profile section across central Newark Basin in the vicinity of Philadelphia, Pennsylvania. (Lyttle and Epstein, 1987, section B-B'.)

Layer V: Newark Strata and Associated Igneous Rocks

In central New Jersey, the filling of the Newark-Gettysburg Basin is a thick (up to 10 km) succession of sedimentary rocks and basalt flows of Late Triassic and Early Jurassic age. The basin-filling strata are collectively called the Newark Supergroup. From the base up these include the Stockton Arkose, Lockatong Argillite, and Passaic (formerly lower Brunswick) Formation. Near the basin-marginal fault, along the northwest edge of the basin, all of these units pass laterally into conglomerates that have been collectively named the Hammer Creek Formation. The three interlayered extrusive sheets of the Watchungs are not present in the Delaware valley, presumably the result of differential uplift and of great post-Newark erosion (Figure 6).

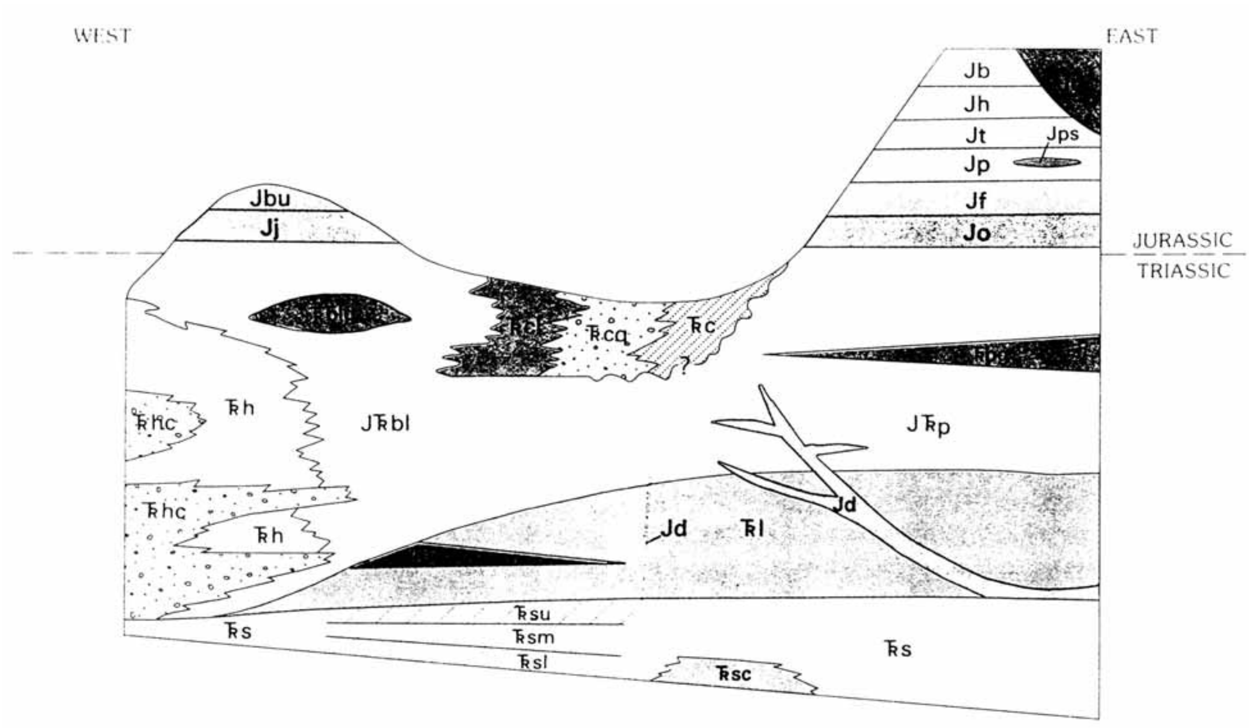

Figure 6. East-west correlation diagram for the Newark and Gettysburg Basins. Note the absence of Watchung extrusives in the Delaware River valley, the result of post-Newark erosion. (Lyttle and Epstein, 1987.)

Delaware River Valley Exposures: Trivializing the Strata Dies

The Delaware River flows in a slightly sinuous path across and at a right angle to the strike of the tilted strata that filled the Newark basin. When the trees are in full leaf as they will be for our trip, they shroud what can be seen on the ground. A first-time visitor to these parts, therefore, may form the impression that exposures are not numerous and are scattered. That this is not so beneath the leaves is indicated by the geologic work of the late Dean B. McLaughlin, an astronomy Professor at the University of Michigan. Each year, Professor McLaughlin took time off from star gazing and spent his summers hereabouts doing detailed stratigraphy and geologic mapping. For more than 30 years, McLaughlin (1933, 1941, 1943, 1945, 1946, 1948, 1963; Drake, McLaughlin, and Davis, 1960, 1967; Geyer, Buckwalter, McLaughlin and Gray, 1963) kept doing this. The geologic map showing numerous units (Figure 7) is based on his careful work.

Figure 7. Geologic map of Triassic rocks along the Delaware River, west-central New Jersey and adjacent Pennsylvania. Mainly after Johnson and McLaughlin (1957) and Drake, McLaughlin, and Davis (1961). Stop numbers refer to trip conducted by F. B. Van Houten. (Van Houten, 1969, Figure 14, p. 331.)

If anyone were skeptical of the general structural relationships that had been worked out earlier by H. B. Kümmel (1890, 1899a, 1940) (See Figure 2.), McLaughlin's maps would suffice to convince them of the reality of the three main fault blocks separated by two large faults (Figure 8). In New Jersey, these are the Hopewell fault on the SE and the Flemington fault on the NW.

In our guidebooks to previous trips in the northeastern part of the Newark basin (On-The-Rocks Trips 05 and 20 (Merguerian and Sanders, 1989, 1991), JES has reviewed the tradition of trivializing the Newark strata. Accordingly, we refer to it only briefly here. By formulating their initial-dip hypothesis, the Rogers brothers offered the ultimate alternative to accepting large thickness numbers for the Newark Group. According to the initial-dip scheme, no usual stratigraphic thickness at all should be assigned to the strata; they were interpreted as large-scale cross strata. Eventually, evidence from primary sedimentary structures demonstrated that the Newark strata had been deposited in horizontal attitudes and subsequently, had been tilted to the northwest. Thus, although the basis for the Rogers brothers' alternative was totally destroyed, their tradition of trivializing the Newark lived on. Nevertheless, McLaughlin's mapping clearly proves that the Newark strata ain't trivial, to coin a phrase.

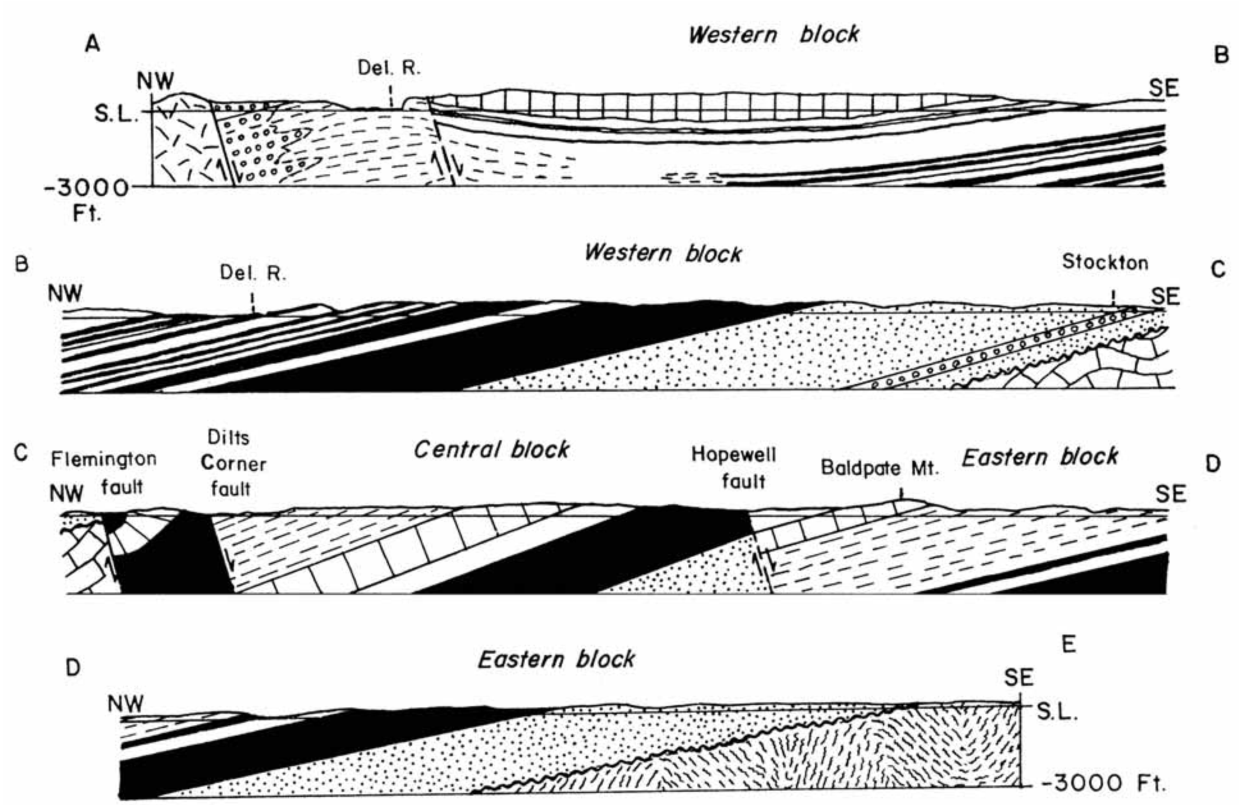

Figure 8. NW-SE profile section across central Newark Basin in Delaware valley showing three major fault blocks. Lockatong Argillite shown in black, intrusives with brick pattern, and pre-Newark unconformity with wavy solid line. (Drawn by J. E. Sanders from Johnson and McLaughlin, 1957, figure 1, p. 8.)

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 structure classes are an exception, luckily, and we can now 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 hear about today. In the following section, we describe folds, faults, surfaces of unconformity, sedimentary structures, structures in sedimentary- vs. metamorphic rocks, and tectonostratigraphic units.

Folds

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. In dealing with the structural geology of 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 behind the creation of folds and faults. At crustal levels below 10 km, the behavior rocks is described as ductile. Folds and faults are accompanied by recrystallization and reorientation of newly formed metamorphic minerals. More on metamorphic textures later. For now let's discuss some geometric aspects of structural geology.

If layers are folded into convex-upward forms we call them anticlines. Convex-downward fold forms are called synclines. In Figure 9, note the geometric relationship of anticlines and synclines. 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 older stratigraphic layers will peek through in the arches of eroded anticlines whereas younger strata will be preserved in the eroded troughs of synclines. 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 terms "antiform" and "synform," which describe the shapes of folds but do not imply anything about the ages of the strata within them.

Axial surfaces of folds physically divide the fold in half. Note that in Figure 9 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.

Realize that in upright folds, 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. The long axes of elongate minerals can also become aligned to produce 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 reoriented remnants of stratification (except of course in the hinge area of folds). Thus, a composite foliation + remnant compositional layering is commonly observed in the field. Departures from this common norm are important to identify as they mark regional-fold hinge areas.

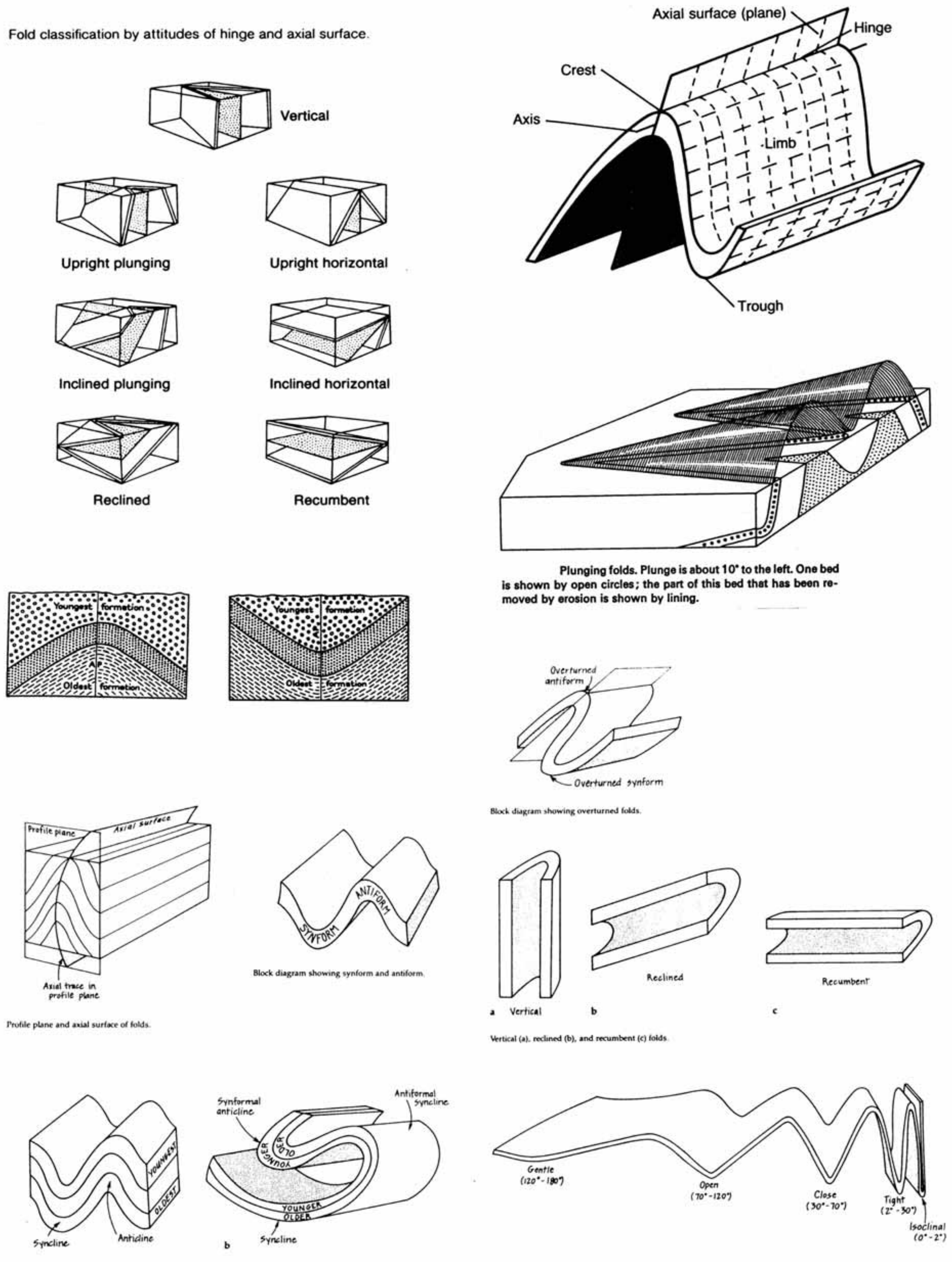

Figure 9. Composite diagram from introductory texts showing various fold styles and nomenclature as discussed in the text.

Folds could care less about the orientation of their axes or axial surfaces and you can certainly imagine that the axial surface of a fold can be tilted, to form inclined- or overturned folds, or be sub-horizontal, to form recumbent folds, all accomplished by keeping the fold axis horizontal. (See figure 9.) In addition, we can keep the axial surface vertical and within it, change the orientation of the axis from horizontal to some angle other than 0° to produce a plunging fold. Such folds can be plunging anticlines (antiforms) or plunging synclines (synforms). Vertical folds (plunging 90°) also occur, in which case the terms anticline and syncline are not meaningful. Most folds in complexly deformed mountain ranges show the effects of more than one episode of deformation and as such their ultimate configuration can be quite complex (i. e., plunging folds with inclined axial surfaces and overturned limbs).

Structural geologists use a relative nomenclature to discuss superimposed products of several episodes of deformation (Dn), folding (Fn), foliation (Sn), and metamorphism (Mn), where n is a whole number starting with 1. 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 geology of an area, for example... "during the second deformation (D_2), F_2 folds formed with the development of an axial planar S_2 foliation under progressive M_1 metamorphic conditions."

Another point about the alphabet soup of structural geology. Seen in cross section, folds fall into one of three groups, the S's, the M's (or W'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 hinge where the M folds or W folds are present.

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

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 loads. 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 inferences than from rock-squeezing data to gain a feel for the complex nature of ductile vs. brittle folding and -faulting. In any case, a few simple relationships are generally agreed upon regarding brittle- and ductile faulting and these are discussed below.

Start with a block of rock and assume that the elastic limit to intracrystalline glide and lattice deformation have been exceeded to the point where the rock begins to behave as a brittle (as in peanut brittle) solid rather than in a plastic (as in toothpaste) manner. Once a failure begins (fracture) it will propagate, produce offset and form a fault surface that will show elongate gouges (called slickensides) that may possess asymmetric linear ridges that enable one to determine the relative motion between the moving sides. The fault block situated below the fault plane is called the footwall block and that situated above the fault plane, the hanging-wall block (Figure 10). With extensional force acting on the sides of the block, the hanging wall will slide down the fault plane producing a normal fault. If the forces are compressive, the hanging wall slides up the fault plane and this results in a reverse fault. A reverse fault with a low angle (<30°) is called a thrust fault. In all of these cases, the slickensides on the fault will be oriented more or less down the dip of the fault plane. These, therefore, illustrate dip-slip motion.

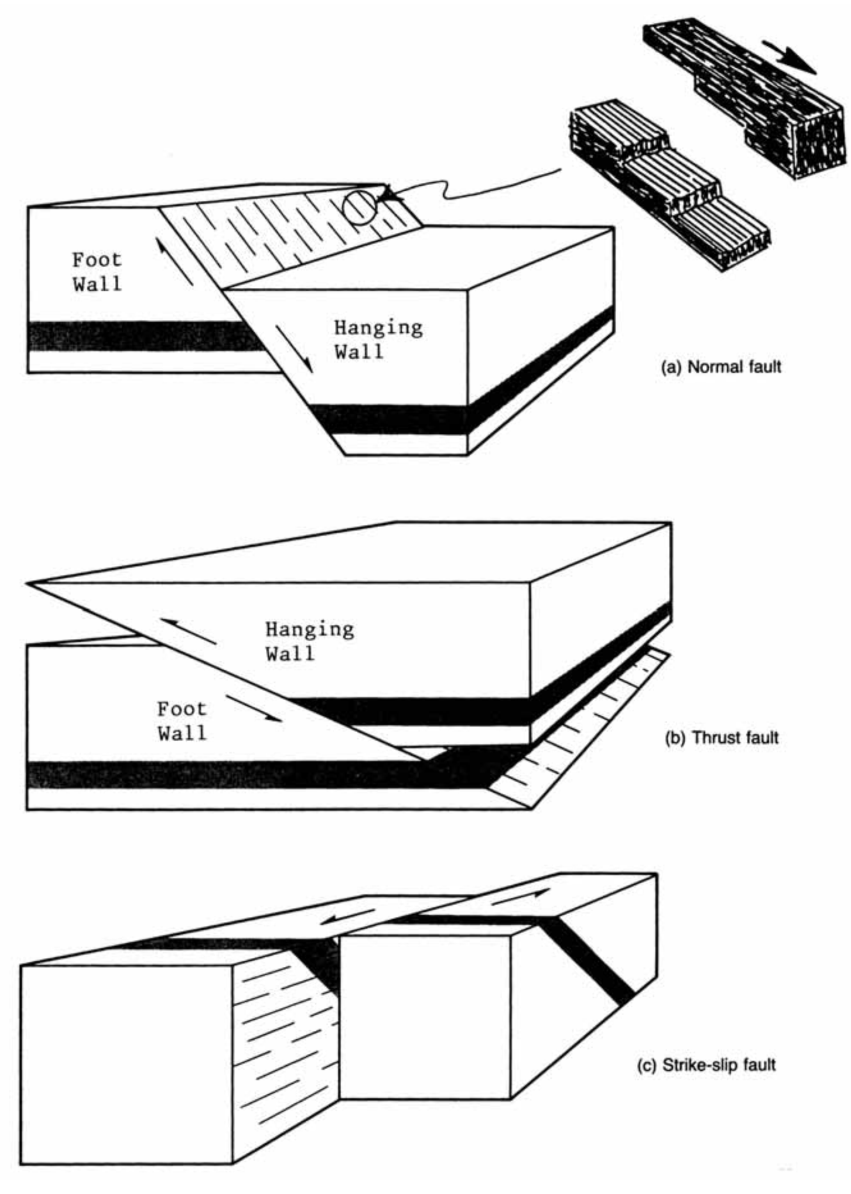

Figure 10. Composite diagram from introductory texts showing the three main types of faults.

Rather than apply extension or compression, suppose one were to shear the block along its sides (i.e., attempt to rotate the block about a vertical axis but do not allow the block to rotate). This type of force will generate a strike-slip fault (Figure 10) with the fault plane showing slickensides oriented subhorizontally. Two, and only two directions of motions are possible: left lateral and right lateral. To determine the sense of motion, imagine that you are standing on one block facing toward the fault so that you can see the opposite block. If the oppposite block has moved relatively to your left, the motion is left lateral. If the opposite block has moved to your right, then the motion is right-lateral. Convince yourself that it matters not which block you choose to observe from! Naturally, complex faults show movements having components of both dip-slip- and of 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.

Tensional- or compressional faulting resulting from brittle deformation, at crustal levels shallower than 10 km, is accompanied by seismicity and the development of highly crushed and granulated rocks called 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. In complexly deformed terranes, such ductile fault rocks can be identified 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) that can easily be "missed" in the field without careful microscopic analysis.

Geologic Structure of the Newark Rocks: Trivializing Lives!

Although most modern geologists might be exude a sense of benign amusement at the Rogers brothers' attempts to avoid the huge scale on which the Newark strata were deposited, they would probably deny that they themselves would ever do such Rogers-style mental gymnastics. But, as a few samples quoted from the recent literature will demonstrate, a powerful tendency exists for presuming that the Newark basin and its filling strata are not products of complicated tectonic circumstances.

One persistent theme is that the faults associated with the Newark rocks follow the structural grain in the pre-Triassic bedrock. Arthur Keith (1923) mentioned this notion early on--he stated that the Newark trends are parallel to the Appalachian trends. Various others have repeated this truism. Lindholm (1978) has based a "model" of the Triassic-Jurassic faulting on pre-Triassic structures. Ratcliffe and Burton (1985) carry this a bit further with their "fault reactivation (sic) models." The "hidden agenda" lurking behind these, and similar, concepts is that because the Newark structures follow older structures, not much post-Newark activity needs to be considered.

In a slightly more-complex variation on this theme, many workers have asserted that a given arrangement of tectonic machinery came into existence, operated for a time, and then stopped. And when the music stopped, lo, and behold! there was the Newark as we see it today, all signed, sealed, and delivered. Three examples in this category are from Van Houten, Manspeizer, and Lyttle and Epstein:

(1) "The Newark basin and its counterparts in eastern North America may have been part of a fracture system initiated by and ultimately destroyed by widening of the Atlantic Basin in Mesozoic time" (Van Houten, 1969, p. 330). In this example, the connection is made between the Newark basin and the widening of the Atlantic Basin. Notice that one setup, the widening Atlantic, does everything required. It starts the fracture system and then destroys the fracture system. In between, presumably, Newark strata are actively deposited, deformed, and then become quiescent.

(2) "From a plate tectonic (sic) viewpoint, Newark-type basins formed along the margin of a plate boundary and in a zone essentially of east-to-west extension. Older faults were activated at this time, creating rift basins whose axes were generally at right angles to the extension direction. One of these, the Ramapo Fault, currently forms the western margin of the basin and has had (sic) a long tectonic history dating back to the Precambrian (Ratcliffe, 1971). Recurrent vertical motion and normal faulting along the fault zone was the dominant dynamic factor influencing the distribution of sediments and volcanic facies, tectonics and morphogenesis along most of the basin. The deepest (sic) and tectonically most active (sic) part of the basin was along the western border fault, particularly in the Watchung Syncline where the youngest (sic) and thickest rift sediments are preserved. North of the Watchung Syncline the basin was relatively stable and only a thin stratigraphic record is preserved (see Ratcliffe, and Olsen this field book)."

"In conclusion, Early Jurassic time was marked by considerably crustal fragmentation, yielding tilted horsts and grabens (sic). The occurrence of isolated synclines with Jurassic rock (at Oldwick, Hopewell, and Jacksonwald) along the Ramapo and the Hopewell faults (both of which show considerable strike slip) suggests that, like the Watchung Syncline, they may represent deep Jurassic structural troughs. This interpretation is compatible with a Dead Sea Rift model, showing the presence of many isolated structural basins (e. g the Dead Sea) within the Dead Sea Rift, a transform fault (sic) extending for more than 1000 km with left-lateral displacement of 105 km (Freund, 1965). That model provides the requisite compressional (sic) and tensional segments along the Ramapo Fault, which is notably offset by en-echelon, oblique-tending (sic) strike-slip faults that cut the basin into rhomb-shaped grabens (Fig. 35). Strike slip along an irregular margin creates an horizon of structural troughs or basins and folds or welts (Fig. 35)" (Manspeizer, 1980, p. 338, 341). [When the English translation of this passage is available, someone please call JES about it, operators are standing by!]

(3) "Several generations of folds may (sic) affect the rocks of the basin, but do not appear to affect the older pre-Triassic rocks outside the basin. The basin may have formed as a pull-apart structure with significant strike-slip movement along the larger faults. This could account for local horsts and grabens within the basin, possible sequential development of different parts of the basin, the compressional regime that produced the folds and local thrust faults, as well as decoupling of the folds within the basin from structures outside the basin. Some of the gently dipping listric normal faults may represent reactivated segments of Paleozoic thrust faults, but with the opposite sense of movement" (Lyttle and Epstein, 1987).

For many years, JES has steadfastly clung to the notion that the tectonic forces that inaugurated the Newark basins were not the same ones that destroyed- and deformed the Newark basin. Put in other words, this means that "something" caused the basin blocks to subside (and not to be rotated nor folded while the thick sediments and interstratified extrusive sheets accumulated). JES contends that another, perhaps totally different "something," put an end to further sedimentation and imposed upon the strata their regional dips (to the NW in the Newark basin in NY, NJ, and PA; to the ENE in the Hartford basin, CT and MA). Other events to be accounted for include: (1) folding of the strata (in such a way that the configuration of the pre-Triassic floor is still generally parallel to the base of the Orange Mountain Basalt) into narrow anticlines and broad synclines, having vertical axial planes and many with fold axes normal to the basin-marginal faults; (2) strike-slip offsetting of these vertical axial planes of folds; (3) several sets of normal (dip-slip) faults; (4) intrusion of one or more sets of postdepositional dikes (and/or generally concordant but locally discordant intrusive sheets).

In 1962, JES published a short article in the journal Science in which he reinterpreted the structure of the Newark basin in terms of postdepositional folds and postfolding faults. In this paper JES argued that along the Hopewell fault, the vertical axial plane of the Somerville transverse anticline had undergone R-lateral strike-slip displacement of 12 miles (Figure 11). He argued that this same fault offsets the basin-marginal Ramapo fault but by only 6 miles. JES took the the 12-mile figure, based on horizontal offsetting of a vertical plane (i. e., the axial plane of the Somerville anticline), the true amount of strike-slip displacement. If true, then because the Ramapo fault is not vertical but dips SE, the amount that 12 miles of horizontal strike-slip displacement on Hopewell fault would offset the Ramapo fault is a function of the dip- and amount of dip-slip displacement (down to the SE) on the Ramapo fault. Given a 12-mile horizontal offset and a dip-slip displacement of 15,000 feet the computed dip of the Ramapo fault is 31°. A dip-slip displacement of 31,680 feet matches a SE dip for the Ramapo fault of 55°.

Manspeizer evidently agrees that strike-slip offsets exist on the Hopewell and Flemington faults (Figure 12), but JES thinks Manspeizer does sufficiently emphasize that the strike-slip offsetting took place after folding, which followed deposition of the Newark strata.

Viewed broadly, all "tectonic philosophers" agree that the region has been affected by two major plate-tectonic cycles: (1) the Appalachian (which lasted throughout the Paleozoic Era and ended about 200 Ma [Ma = Million years ago]), and (2) the Atlantic (which began about 175 Ma and is still in progress). JES infers that in between these two large cycles was what he calls a "switchover tectonic interlude" (having a duration of about 30 Ma) during which the Late Triassic-Early Jurassic faulting, basin formation, basin filling (including several episodes of mafic volcanism) and basin destruction took place. The destruction of the Newark basin was associated with the mid-Jurassic deformation (which involved elevation and reversal of drainage out of the former basins and several episodes of normal faulting, of folding, of strike-slip faulting, and of igneous activity). This JES interpretation of the plate-tectonic significance of the Newark rocks differs significantly from numerous published assertions that the Newark episode of "rifting" accompanied the nascent stages of the Atlantic cycle. This point of view is typified by the following statement by Emery and Uchupi (1972, p. 93): "All of the Triassic basins are believed to be tensional structures related to the opening of the Atlantic Ocean basin." Note, the key words here are: "are believed to be."

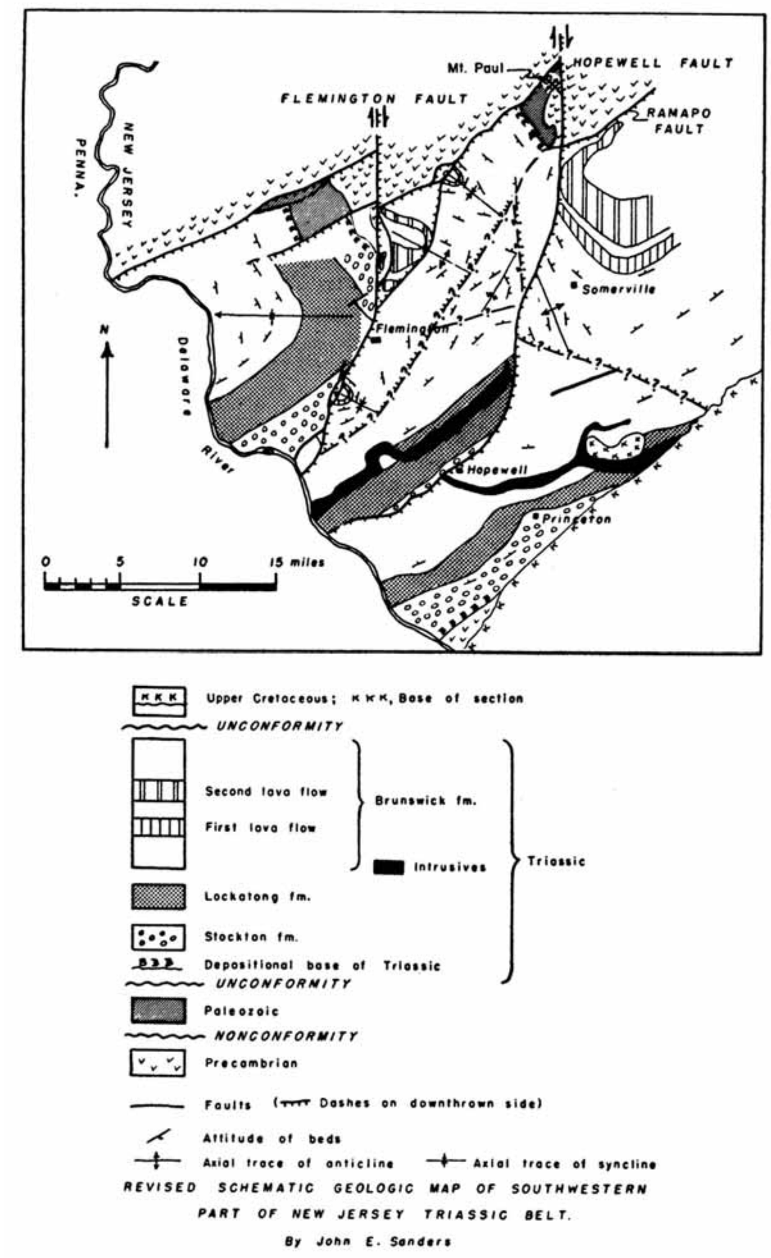

Figure 11. Revised schematic geologic map of the southwestern part of the New Jersey Triassic belt showing major structures and inferred northward extensions of the Hopewell and Flemington faults. Relationships of these faults to "offsets" of the Ramapo fault are shown according to the interpretation of right-lateral strike-slip displacement on the Hopewell and Flemington faults. (Sanders, 1962, Figure 2, p. 41.)

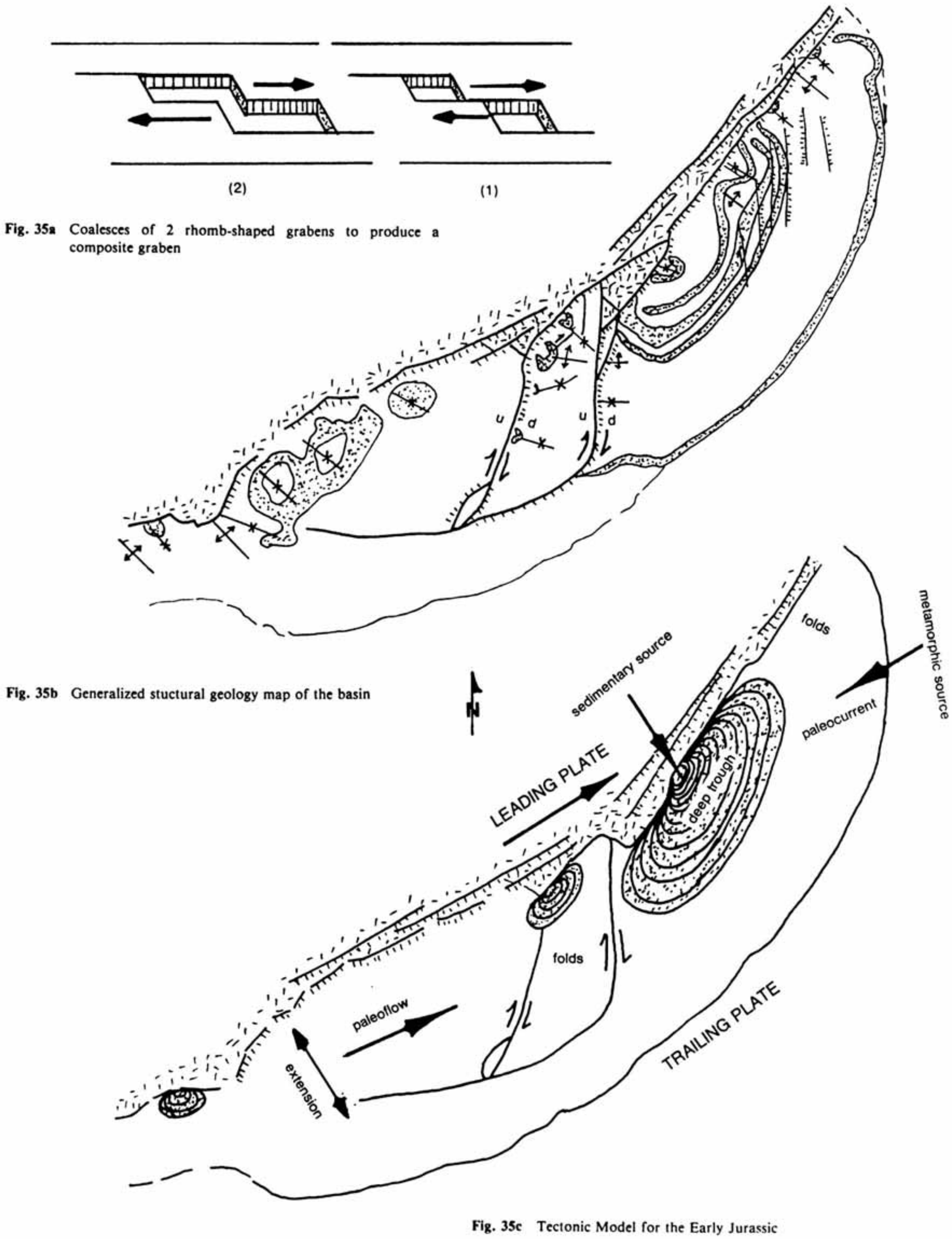

Figure 12. Tectonic model for development of Newark Basin according to Manspeizer (1980, figure 35, p. 342) wherein sediment fans fill basin during regional extension. At the same time(?) strike-slip faults cut basin into a series of fault-bounded rhomb-shaped grabens.

The Late Triassic-Early Jurassic episode in the history of the region culminated with a noteworthy terminal orogeny, the significance of which has either been overlooked completely or relegated to the insignificant category.

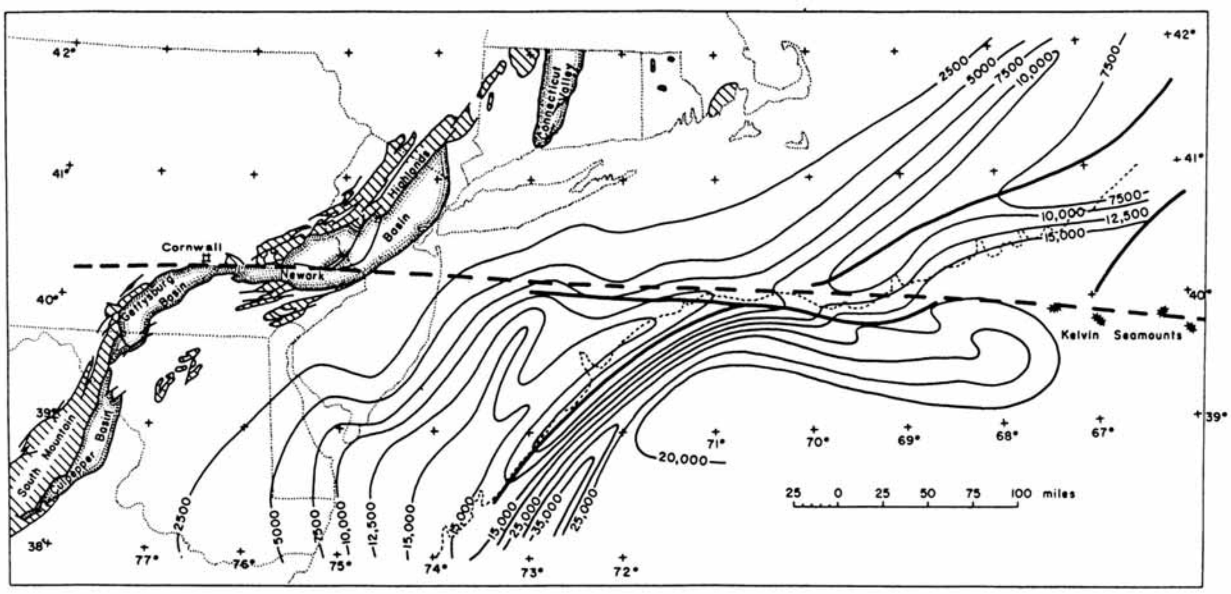

Figure 13. Map of central Atlantic states and adjoining continental shelf showing relationship of postulated Cornwall-Kelvin Displacement at about 40°N to trends of Triassic rift valleys (stippled) and major Proterozoic crystalline massifs (oblique lines), and to basement topography (solid thin lines, depth in feet) and magnetic anomaly pattern (solid heavy lines) of the shelf (after Drake and Woodward, 1963). According to Van Houten (1969), from whom this figure was pilfered (Figure 12, p. 329), the Cornwall-Kelvin Displacement shows 75 to 100 miles of right-lateral strike-slip offset.

It is JES' interpretation that after nearly 175 years of groping in the dark, we finally possess a conceptual framework (plate tectonics) whose scope is large to render the Newark episode comprehensible. What is more, plate tectonics allows us to explain all the post-Early Jurassic, pre-Cretaceous tectonic activity in terms of the sequential application of three regional strike-slip couples. The characteristics of these couples and their locations are:

1. Right-lateral shear oriented E-W, concentrated along latitude 40°N (Figure 13).

2. Right-lateral shear oriented N-S, concentrated along longitude 73°W.

3. Left-lateral shear oriented NE-SW, concentrated along the median longitudinal axis of the Newark outcrop belts.

Judging by the evidence on Staten Island, where Upper Cretaceous sands truncate and bury tilted- and eroded Newark strata, all the deformation involving Newark rocks had been completed by Late Cretaceous time. In the subsurface of Georgia, however, Newark strata underlie Lower Cretaceous sediments (which means that the deformation of the Newark had been completed by Early Cretaceous time). The episodes of deformation of the Newark strata are inferred to have been deep seated and to have involved chiefly the basement rocks. The Newark strata participated rather passively. In post-Early Jurassic, pre-Cretaceous time, enough thickness of the continental lithosphere was removed to create regional gravity anomalies that are positive where the top of the mantle lies closer to the surface.

The problem of the former extent of the dipping Newark strata at their truncated updip edges remains unresolved to the satisfaction of investigators. JES personally prefers the interpretation that the depositional basins were large grabens. If the graben-basin interpretation is correct, then remnants of the Hartford basin should be present beneath western Long Island. Only one water well (the validity of which has been disputed) and Woollard's (1943) regional gravity map support the interpretation that Newark strata underlie the Upper Cretaceous sands and -clays beneath Long Island in a position that one would predict from the large-graben hypothesis. The presence of feldspathic sediment derived from the southeast of the present belt of outcrop of the NW-dipping strata of the Newark basin and having a K-Ar age of about 350 Ma and demonstrably transported northwestward (a direction that is down the present dip) has been cited as evidence that the former extension of the truncated Newark strata to the SE ranges from small to zero. According to the large-graben hypothesis, this feldspathic sediment was indeed derived from the SE and was transported northwestward from 350-Ma pre-Newark parent rocks that formed the SE wall of the graben SE of the Hartford basin. Until detailed provenance studies have been made of the mineral particles it will not be possible to decide with assurance whether the minerals came from the nearest exposure of 350-Ma pre-Triassic rocks SE of the present belt of outcrop of the NW-dipping strata of the Newark basin or from sites beneath Long Island, as is argued here.

Layer VI: Coastal-plain Sands and Clays of Late Cretaceous Age

The strata underlying the coastal plain began to accumulate after the Atlantic Ocean began to open and eastern North America had become a passive continental margin. The regime thus established mirrors the kind of setting that prevailed during the deposition of the Lowerre Quartzite and Inwood Marble.

The coastal-plain strata consist of sands that have been cemented only locally (the hematite-cemented sandstones and conglomerates, or "ironstones"), and the interbedded clays have not become fissile. Hereabouts, the exposures show only the Upper Cretaceous part of the sequence. Elsewhere, however, younger units are present. The youngest widespread marine unit in the coastal-plain succession is of Miocene age.

A characteristic of the coastal-plain sands is their great mineralogic maturity. They generally lack feldspar and contain only quartz and resistant varieties of heavy minerals, such as zircons. Notably absent are any particles derived from the Newark Supergroup. The absence of Newark debris supports the conclusion that the coastal-plain strata formerly extended far enough inland to bury the Newark outcrop areas. Some of the distinctive heavy minerals show that the crystalline central core of the Appalachians was not covered, but was providing debris. Simiarly, sand composed of serpentinite particles indicates that the Staten Island serpentinite body was exposed.

The coastal-plain strata belong to the large category of basin-margin sediment fillings whose interpretations have been revolutionized as a result of new concepts of seismic stratigraphy. These new concepts have grown out of detailed analyses of the new generation of continuous seismic-reflection- profile records collected from moving research ships. Instead of confining the analysis of the seismic records to evidence of buried geologic structures, the chief goal of seismic surveys and the only point of interest by most geophysicists, a group of geologists at the Exxon Research Laboratories in Houston, TX, under the leadership of Peter Vail, have shown how these new seismic records contain evidence of the profound influence exerted by changes of sea level on the sedimentary strata that accumulate at the margins of the oceanic basins. Analysis of data from passive continental margins collected worldwide has enabled Vail and his co-workers to compile a sea-level curve.

The notion that the stratigraphic record exposed on the continents records numerous changes of sea level had been proposed early in the 20th century, by the American geologist A. W. Grabau (1906, 1913, 1924, 1936, 1940) among others and various European geologists such as the Termier's or Umbgrove. Subsequently, the pendulum of geologic fashion in interpreting strata swung in the opposite direction and the effects of sea-level changes were not much emphasized. But, now it's back to Grabau and then some, but with one difference: the new "young Turks" think that they invented (not re-invented) the great wheel. They do not mention Grabau, T. C. Chamberlin, Charles Schuchert, E. O. Ulrich, or Stuart Weller, to name a few of the notable early American proponents of the interpretation that the continental stratigraphic record had accumulated in response to numerous, extensive changes of sea level. To be sure, the main emphasis of many of these early American studies was to use the gaps in the stratigraphic record as boundaries between systems, for example. In contrast, armed with the new regional look made possible by the seismic-profile records, the seismic stratigraphers are able to show how sea-level changes are expressed--not only in the areas where formerly the breaks resulting from an episode of emergence were emphasized but also in the basins, where deposition was continuous. The seismic expression of strata deposited at a high stand of the sea differs from that of strata deposited at a low stand. Therein lies the secret of success of the new interpretations.

Given such a powerful stimulus, nearly all stratigraphers are now reevaluating their data in terms of sea-level changes. An example is R. K. Olsson's (1988) use of benthic Foraminifera from the Upper Cretaceous in the coastal plain of New Jersey for making estimates of paleodepths of the Cretaceous sea. Late in the Miocene Epoch, the coastal-plain sands and -clays were elevated and truncated by erosion to form a surface upon which the Quaternary glaciers acted.

So much for the geologic background. Now on to the objectives of today's wild- and wooly field trip.

OBJECTIVES

1) Study type sections of Stockton and Lockatong formations in the south-central part of the Newark Basin.

2) Observe facies changes between basin-marginal rudites and finer-textured strata away from the basin margin.

3) Examine evidence for lake-level control on sediments in the Lockatong Formation.

4) Study the effects of mid-Jurassic deformation, notably the evidence that significant strike-slip faults are present, and,

5) Try to avoid eating the hot dogs at Stop 5.

LIST OF LOCALITIES TO BE VISITED

Stop 1: Dolerite quarry, Belle Mountain, NJ.
Stop 2: Faults in Lockatong Formation, Lambertville, NJ.
Stop 3: Solebury Conglomerate, Stockton, NJ.
Stop 4: Lockatong Formation, Byram, NJ.
Stop 5: Passaic Formation, Frenchtown, NJ.
Stop 6: Rudites in Passaic Formation, Gravel Hill, NJ.

ROAD LOG AND DESCRIPTION OF LOCALITIES (STOPS)

Mileage **Remarks**
Ind. Cum.

Log begins at tollgate entrance to NJ Turnpike.

0.5 0.5 Passing ramp on R to Alexander Hamilton service area.
1.4 1.9 Passing on R what is left of a stock-like mass of dolerite associated with the Palisades sheet.
0.4 2.3 On bridge over Hackensack River, Meadowlands.
0.7 3.0 End of bridge; view ahead to greater downtown Newark.
0.5 3.5 Passing ramp on R for Exit 15 W, I-280 (Kearny and The Oranges).
0.9 4.4 View on L of the Pulaski Skyway (road from Holland Tunnel).
0.5 4.9 Passing beneath Pulaski Skyway.
0.3 5.2 Passing ramp on R for Exit 15-E (to Newark).
0.6 5.8 NJ Turnpike divides; on L for cars only.
1.2 7.0 Big sign on R for Hernia Center.
0.7 7.7 Passing on R Exit 14, 14A, 14B, 14C, for I-78, US Route 1, US Route 22 (Newark Airport, Newark, etc.)

0.8 8.5 Passing close to airport runway on R; loading cranes for containers at Port Newark/Elizabeth on L.
1.0 9.5 The wooded hill on the distant horizon to the L is Todt Hill, Staten Island, the highest natural point in New York City. The level of the top of the Palisades ridge has been descending to the S; opposite here, it is at sea level.
1.1 10.6 Passing Exit 13 on R, to I-278, Verrazano Bridge.
0.3 10.9 Passing beneath road above to Goethals Bridge.
2.8 13.7 Tank farms as far as the eye can see.
0.5 14.2 Passing Exit 12 on R, to Carteret and Rahway.
2.5 16.7 Passing beneath powerlines; watch out for AC magnetic fields! Please note that high tension wires in the northeast were constructed in 1956 after the 1954 attack of Godzilla on Tokyo, Japan.
0.4 17.1 Passing ramp on R for Thomas A. Edison service area.
0.5 17.6 Passing ramp on R for Exit 11, Garden State Parkway, US Route 1, US Route 9, (Woodbridge and The Amboys).
3.3 20.9 Passing ramp on R for Exit 10, I-278 and NJ 440 (Metuchen, Edison Township, and Outerbridge Crossing).
0.7 21.6 New York Times printing plant on L.
3.4 25.0 Bridge over Raritan River. View on L shows a capped landfill. View to R of arch bridge for AMTRAK (nee Pennsylvania) RR tracks.
0.4 25.4 Passing ramp on R for Exit 9, US Route 1 and NJ 18 (New Brunswick, East Brunswick and shore resorts).
9.5 34.9 Passing BASF complex on R.
0.3 35.2 Passing ramp on R for Exit 8A (Jamesburg, Monroe, Cranbury, and South Brunswick).
1.3 36.5 End of divided roadways; lanes merge.
0.9 37.4 Leave New Jersey Turnpike via ramp on R for Molly Pitcher service area. [Twenty-minute pit stop.] Re-board vans; on to S.
5.2 42.6 Passing ramp on R for Exit 8, NJ 33 (Hightstown and Freehold).
7.0 49.6 Exit from NJ Turnpike via ramp on R for Exit 7A, I-195 (Trenton, shore points, and Great Adventure).
0.4 50.0 Stop. Toll barrier. Pay up. After passing toll gate, move L for I-195 W, toward Trenton.
0.2 50.2 Enter ramp on L for I-195 W.
0.5 50.2 Entering I-195 westbound.
1.1 51.3 Passing Exit 5B on R, US Route 130 N (New Brunswick).
0.2 51.5 Passing Exit 5A on R, US Route 130 S (Bordentown, I-295).
1.3 52.8 Passing Exit 3A on R (Yardvillle).
1.4 54.2 Passing Exit 2 on R, US Route 206 (S. Broad Street and Arena Drive).
0.4 54.6 Take exit ramp on R to I-295, to US Route 1, I-95; Milepost (MP = 0.5).
1.1 55.7 Passing beneath Clinton Avenue overpass.
0.4 56.1 Passing Exit 61A on R (Arena Drive E; White Horse Avenue)
0.1 56.2 Passing Exit 61B on R (Arena Drive W).
2.2 58.4 Passing Exit 63A-B on R (NJ 33, Co. 535, to Mercerville and Trenton).
1.5 59.9 Passing Exit 65A on R (Sloan Avenue E).
0.1 60.0 Passing Exit 65B on R (Sloan Avenue W).

0.6 60.6 Passing MP 66 on R.
0.2 60.8 Passing over AMTRAK RR tracks.
0.3 61.1 Entering Lawrence Township (sign on R).
0.7 61.8 Passing Exits 67A-B, Junction US Route 1 to I-95 N on R.
1.2 63.0 Passing Exit 68A on R (Co. 583, Princeton Pike N).
0.2 63.2 Passing Exit 68B on R (Co. 583, Princeton Pike S).
0.6 63.8 Passing beneath powerline.
0.2 64.0 Passing Exit 69A on R (US Route 206 N)
0.2 64.2 Passing Exit 69B on R (US Route 206 S)
0.5 64.7 I-295 becomes I-95. (We are -200 here.)
0.9 65.6 Passing Exit 71A on R (Federal City Road N).
0.1 65.7 Passing Exit 71B on R (Federal City Road S).
1.1 66.8 Passing Exit 4 on R (NJ 331, Ewing, Pennington).
0.6 67.4 Entering Ewing Township (sign on R).
0.5 67.9 Passing beneath CONRAIL tracks on bridge above I-95.
0.3 68.2 Entering Hopewell Township (sign on R).
0.1 68.3 Passing ramp for Exit 3 on R (Scotch Road).
0.7 69.0 Re-entering Ewing Township (sign on R).
0.9 69.9 Passing ramp on R for Co. 579 (Harbourton, Mercer Co. Airport, Trenton); outcrop on R of Newark red siltstone.

We have just entered the easternmost of three belts of outcrop of the Newark basin-filling strata. The base of the strata within the easternmost belt are in contact (either stratigraphic--nonconformable, or fault) with pre-Newark rocks. The other two belts are separated by faults having large stratigraphic displacements and about which differences of opinion exist. We will be studying one of these faults at Stop 2. According to Johnson and McLaughlin (1957 guidebook to a similar trip conducted in association with the annual meeting in Atlantic City of the Geological Society of America, p. 48): "The State House foundation rests upon the Wissahickon formation (Proterozoic?), and one quarter of a mile northwest, where we pass under the approach to the Calhoun Street bridge, the road is underlain by the Chickies formation of Early Cambrian age. Gabbro, intrusive in the Baltimore gneiss (Proterozoic), can be found just to the north between the East-West Thruway and State Street, but less than a half mile farther we pass over the basal beds of the Stockton formation of Triassic age. The contact between the Stockton and the underlying Baltimore gneiss has been exposed several times within recent years on the east side of Trenton where it dips northwest at about 15 degrees, the same rate as the overlying beds. The latter strike N50°E and are characterized by occasional well-rounded pebbles of blue quartz--derived from the underlying gneiss--ranging up to 3 inches in maximum diameter. Where the contact was last observed, the underlying material was (sic) and disintegrated to a depth of several feet."

A key point mentioned by Johnson and McLaughlin is that the dip of the contact surface at the base of the Newark is about 15° "the same rate as the overlying beds." We emphasize this point, because the literature is full of references to the idea that the tilted Newark beds were deposited on a fault block that was being tilted as it was displaced. Such fault blocks do exist, but their diagnostic feature is that the dip of the basal surface is significantly greater than the dip of the uppermost strata.

In West Trenton, however, the SE contact of the Newark strata is a fault having a throw of several hundred feet (discovered about 1940 by the drilling of several deep wells) (according to Johnson and McLaughlin, 1957, p. 59).

1.3 71.2 Leave I-95 at Exit 1, NJ 29 (Trenton, Lambertville); merge into NJ 29 going NW parallel to Delaware River (on L).
0.4 71.6 Bernard Drive on R.
0.5 72.1 Delaware Avenue on R.
0.4 72.5 Co. 637 (Jacobs Creek Road) on R. According to Van Houten (1969, p. 332) Analcime-rich reddish-brown uppermost Lockatong Formation crops out in deep ravine. Belt of Brunswick Formation to N is about 4 miles wide. Local exposures on E side of road."
0.5 73.0 Haddock Road on R.
0.1 73.1 Passing MP 11 on R.
0.5 73.6 Exposure on R of red siltstone in lower part of Passaic Formation (next above the Lockatong Formation), dipping NW.
0.5 74.1 Traffic light, Washington Crossing; Co. 546 (to Pennington on R; to Newtown, PA via bridge on L. Old canal visible on L, alongside of and between NJ 29 and the Delaware River.
0.5 74.6 Union Fire Dept. building on R.
0.2 74.8 Leave Pennington quadrangle, enter Lambertville quadrangle.
0.3 75.1 MP 13 on R.
0.1 75.2 Traffic light, Church Road, Titusville. Hill on R ahead is Baldpate Mountain, an intrusive.
1.7 76.9 Road on R, entrance to a trap-rock quarry. According to Van Houten (1969, p. 332, his mileage 10.7: "Old quarry in Baldpate Mountain diabase. This intrusion (sic) in the Brunswick Formation [now Passaic Fm.--JES], as the others along the traverse, apparently is a faulted part of the Palisades Sill."
0.5 77.4 Pleasant Valley Road on R follows Moore Creek. According to Van Houten (1969, p. 332, his mileage 11.0): "Southern Branch of Hopewell Fault crosses river and continues west as the Buchmanville Fault."
0.5 77.9 Dolerite quarry on R. (Belle Mountain).
0.2 78.1 Pull over to R, near chain link fence and weathered exposure of igneous rock for Stop 1.

STOP 1 - Dolerite quarry, Belle Mountain. [UTM Coordinates: 506.4E / 4464.6N, Lambertville quadrangle.]

The mafic igneous rock exposed here is a deeply iron-stained diabase (medium-textured gabbro) with significant K-feldspar in the form of orthoclase and/or anorthoclase based on our hammer and hand-lens investigation. Because of their tan color, the feldspars are obvious in weathered specimens. Petrologists call such rocks granophyres which are known to be present in small amounts at all levels in mafic sills and can constitute up to 25% volume in thick sills.

Cutting through the diabase are prominent fractures oriented N30°W, 80°NE and spaced roughly 10 cm apart. We suspect they are not columnar cooling joints but structural fabrics related to faulting. These fractures cut an older set of healed microfaults characterized by roughly 1-mm thick, dark-green- to black, chloritized gouge zones oriented N50°E with steep SE dips. These older, fault-related gouge zones exhibit subhorizontal slickensides with a gentle pitch. Locally, these surfaces have been overprinted by steep, dip-slip slickensides indicating that the tectonic displacement changed from strike slip to dip slip. We will observe this same relationship again at Stop 2. Reboard vans and continue ahead.

0.4 78.5 Valley Road on R.
0.4 78.9 Golden Nugget Flea Market on R.
0.2 79.1 Lambertville Restaurant on R; leave Mercer County, enter Hunterdon County.
0.4 79.5 Outcrop of Passaic Formation on R. According to Van Houten (1969, p. 332, his mileage 12.8): "Lambertville Sill rises to Goat Hill (altitude, 450 ft) at south end; crosses the river and forms Solebury Mt. Brunswick [now Passaic--JES] hornfels just above the contact south of town includes a tourmaline-rich facies; south of New Hope, Pennsylvania, on the west bank, metamorphosed cyclic drab (sic) deposits include grossularite-prehnite-muscovite hornfels."

0.4 79.9 More outcrops of Passaic Formation on R.
0.2 80.1 Divided highway begins at E end of Lambertville.
0.3 80.4 According to Van Houten (1969, p. 332, his mileage 13.8) we here are: "Crossing approximate top of Lambertville Sill (1,800 ft thick)."
0.3 80.7 Y-shaped intersection, NJ 29 follows L branch. According to Van Houten (1969, p. 332, his mileage 14.1): "NW-dipping Brunswick [now Passaic--JES] hornfels in roadcut to E just south of Rt. 518."
0.3 81.0 Traffic light, Main and Bridge Streets, Lambertville. Continue ahead on NJ 29.
0.7 81.7 NJ 29 becomes wider. Leave Lambertville quadrangle, enter Stockton quadrangle.
0.3 82.0 Turn R into ramp for US Route 202 N. Somewhere here we cross the Dilts Corner fault, which brings up the Lockatong on the W side against the Passaic Formation on the E. side.
0.2 82.2 Turn R again for entrance ramp to US Route 202 N.
0.1 82.3 Park vans at far end of ramp for Stop 2.

STOP 2 - Superposed faults in deformed Lockatong Formation (Lower Jurassic part of Newark Supergroup) along cuts for new US Route 202. [UTM Coordinates starting at 504.7E / 4470.0N, Stockton quadrangle.]

According to some geologists, the rocks filling the Newark basin have been subjected only to regional tension. Accordingly, deformation should consist of simple block faults. We plan to visit several localities along these US 202 cuts, where the road cuts across a significant fault zone that affects gently dipping Newark strata.

The first thing we shall examine is a fault that has made a gouge zone about 0.5 m thick. Present within the fault zone are beautifully transluscent, greenish fault-mirror slickensides (called "slickentite" by California geologists) with local white zeolite minerals on the faces. This fault strikes N30°E and dips 77°NW. Slickensides within this fault plunge 09° into S30°W.

Steep dip-slip slickensides locally overprint these chloritized subhorizontal slickensides and are related to small faults varying in orientation from N30°W, 70°SW to N15°W, 90°. These faults display dip-slip motion with slickensides overprinting the chlorite in the fault mirror. Large-scale "corrugations" or undulations in the rock faces plunge 05°into S10°E. We infer that these are related to the older, strike-slip teconic episode. Farther down the ramp, low-dipping strata are evident.

Take a closer look and walk down the ramp we just drove up. About 150 m from the vans notice the "mega-corrugations" (slickenside-like features) on the vertical rock face (here, the rock face strikes N32°E). CM spotted these and infers that one can use the systematic pattern of the asymmetrical small dull step faces to show right-lateral strike-slip motion. These dull faces contrast with the mirror-like slickenside surfaces.

0.1 82.4 Continue northbound on US Route 202.
0.1 82.7 Low-dipping Lockatong argillite in cuts on R. Notice the dark reddish color of the Lockatong Formation which is here cut by many fractures. More examples of large-scale "mega-corrugations" from strike-slip faulting overprinted by dip-slip motion. On our pre-trip investigation (6/10/93), CM took a photo of the fractures by lush patch of poison ivy - watch for it on the trip! Fractures strike N15°E and dip 80°SE with slicks pitching 45° toward the N indicating right-lateral oblique slip faulting. Note that the bedding is indicated only by color changes as bedding-surface partings are not present.

0.1 82.8 Rocks in this cut are less deformed; they show shale partings and steep blocky joints.
0.4 82.8 Crossing beneath powerline.
0.1 82.9 Crossing beneath second powerline.
0.1 83.0 More Lockatong in cuts on both sides of US Route 202; notice changed orientation of bedding (strike E-W, dip 22°N).
0.8 83.8 More red Lockatong exposed both sides; blocky joints are most-prominent partings. (According to Van Houten, 1969 guidebook, the red Lockatong layers are rich in the sodium-zeolite mineral analcime.)
0.3 84.1 Take exit ramp on R (Mount Airy and Dilts Corner).
0.3 84.4 Stop at end of ramp, turn L (in the direction of Dilts Corner).
0.2 84.6 Passing beneath US Route 202; just beyond, turn L into ramp for southbound US Route 202.
0.4 85.0 Merging with southbound lanes of US Route 202.
0.1 85.1 Pull over to R; stop and examine rocks by US Route 202 sign. (Yes, Mabel, we are still at Stop 2.)

Here, uniformly spaced fractures are 3 to 4 cm apart; they strike N27°E and dip 68°NW. The minerals facing the joints include calcite, quartz, and specular hematite(!). Near the N end of the exposure, green slickensides on a fault surface striking N3°E and dipping 85°W pitch to the S at 47°. Small anastomosing fracture zones about 1 cm thick feature limonite (pseudomorphic after hematite?).

The view across the highway is of prominent steep joints, which are the most-prominent parting in the rocks. These fractures strike N35°E and dip 70° NW. On the W side of the highway, bedding strikes N35°W and dips 20°NE. Reboard vans and continue to S on route 202.

0.3 85.4 Passing MP 2 on R.
1.2 86.6 Exit to R on ramp for NJ 29 (Lambertville and Stockton).
0.2 86.8 Stop at end of ramp; turn L.
0.1 86.9 Passing under US Route 202.
0.2 87.1 Stop sign; Junction NJ 29; turn R toward Stockton.
The rail line here follows Alexauken Creek, whose valley lies along one of the fault zones that repeat the Lockatong Formation.
0.1 87.2 Passing beneath US Route 202 again; powerline crossing.
0.6 87.8 RR crossing for spur line to quarry at Mt. Gilboa. According to Van Houten (1969, p. 332, his mile 16.3): "Mt. Gilboa quarry in very coarse-grained diabase (gabbro). Lockatong hornfels on south edge of quarry at entrance to property.
0.3 88.1 MP 21 on R.
0.4 88.5 Turnout on R; old entrance to quarry fenced off.
According to Van Houten (1969, p. 332, his mileage 16.9: "Lockatong nepheline-cancrinite hornfels above diabase intrusion (sic). Nepheline (sic) and analcime syenites crop out along small creek to E (fig. 15). Barker and Long (1968; 1969 in press)/(p.333) have proposed that these syenites formed by reaction of Lockatong Argillite with a granophyric differentiate of diabase." Loyalist On-The-Rockers who have visited the Graniteville quarry, Staten Island, may recall the granitoid rock formed there where a xenolith of Lockatong Formation reacted and fused within the Palisades magma.

At some point between here and Brookville, coming up, is the Flemington fault. Stockton conglomerate dipping NW crops out 1/8 mile S of Brookville; Lockatong argillite is present ca. 100 yards to the S (Johnson and McLaughlin, 1957, p. 61). According to Van Houten (1969, p. 333, his mileage 17.2), the Flemington fault "continues west as the Furlong Fault which uplifted Cambro-Ordovician limestone is overlain by the Stockton Formation. The fault block is about 17 miles wide".

0.2 88.7 Start Z bend in NJ 29, Brookville. In the hillside N of the highway are exposed strata of coarse conglomerate (the Solebury Member) near the base of the Stockton formation. Quartz- and quartzite pebbles range in diameter up to cobble size.
0.8 89.5 Just after church on R, turn R into fenced-in playground of Stockton School for STOP 3.

STOP 3 - Conglomerate and interbedded sandstone in Solebury Member of Stockton Formation exposed in woods adjacent to the Stockton Borough School. [UTM Coordinates: 502.1E / 4472.5N, Stockton quadrangle.]

Essentially monomict quartz-pebble rudites with intercalated coarse, cross-bedded sandstones are exposed at this locality. Marlene Leeb, Chief School Administrator, who was nice enough to permit access to this exposure, has asked us not to remove samples. Rounded, ellipsoidal pebbles of quartz (quartzite?) are up to 8 cm in long dimension in a matrix-supported conglomerate. Note the lack of carbonate clasts (compared with Stop 6, later today). The pebbles are aligned with their widest dimension lying flat within the layering of the enclosing sands with bedding oriented N25°E, 20°NW. Large-scale cross beds are evident in the sandy matrix. Measurements of cross beds suggest a component of flow in the direction S70°W. Elsewhere channels at the base of the rudites are oriented N10°W.

The matrix is internally layered and mostly quartzose but occasional particles of tan-weathering feldspar (up to 1 cm in size) are found upon close examination. At the base of the exposure, deeply recessed under the lowest ledge, is a layer of red siltstone that is free of pebbles. The conglomerates and intercalated sandstone cuts at a low angle across bedding in the red siltstone. We suspect that the siltstone/conglomerate contact marks the base of an upward-fining sequence and that the influx of rudites and coarse, cross-bedded sands are the result of storm-related sheet flows. The tectonic joints here are oriented N38°E, 80°NW.

Distance-and-dip computations assuming no faults indicate this exposure lies 1060 feet above the base of the Stockton (Figure 14).

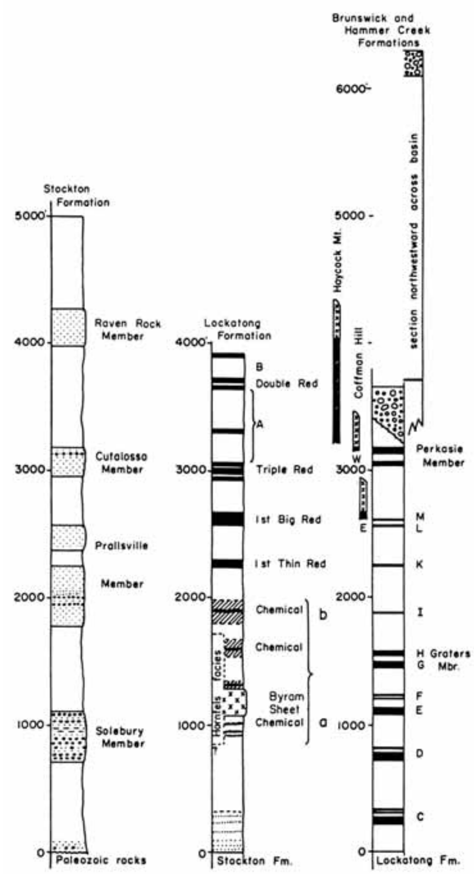

Figure 14. Columnar section of Newark Supergroup along the Delaware River from Stockton to a point three miles west of Milford, New Jersey. See also Table 4. (Van Houten, 1969, figure 3, p. 316; based on McLaughlin, 1943, 1944, 1945, 1946, and Van Houten, 1964.)

0.0 89.5 Turn R leaving schoolyard; continue on NJ 29.
0.1 89.6 Colligan's Stockton Inn on R at street to bridge; continue on NJ 29.
0.1 89.7 L turn in NJ 29 at junction with Co. 523.
0.6 90.3 Road junction at Prallsville; ignore Co. 519 on R; go L on NJ 29 toward Raven Rock and Frenchtown.
0.1 90.4 According to Johnson and McLaughlin (1957, p. 61) a vein containing the uranium mineral torbernite in a limonitic rock "crosses the highway but cannot be traced more than a hundred feet". Chemical analyses of four selected samples collected by the United States Geological Survey in 1950 showed a uranium content ranging from 0.09 to 1.28 percent.

0.3 90.7 Passing old quarry in "brownstone" on the R. This was Stop 3 of the 1957 Geological Society of America trip. "Fine-grained reddish-brown sandstone alternated with medium (sic) to coarse-grained yellow (sic) and light-gray arkose" (Johnson and McLaughlin, 1957, p. 61).

According to Van Houten (1969, p. 333, his Stop 1, mileage 18.9): "Quarry in Stockton Arkose, upper Prallsville Member, 200 feet thick; 2,500 feet above base of the formation." Features that can be seen here include:

1. Arkose, medium, well sorted; gray to yellowish gray; rel. little associated mudstone.
2. Na/K feldspar ratio commonly is 2:1.
3. Thin reddish-brown mudstones show channels.
4. Cross strata, large and small.
5. Micro-placers of specular hematite after magnetite.
6. Small yellowish-brown spots (goethite here; elsewhere, an iron-stained carbonate mineral).
7. Thin mudstones, micaceous, reddish brown.
8. Burrows are present, esp. in mudstones; on soles of arkose, horizontal tunnels.
9. Mud chips are present on sloping cross strata.
10. Near top of quarry, coarse kaolinitized arkose.

0.4 91.1 Leave Stockton quadrangle, enter Lumberville quadrangle.
0.2 91.3 MP 25 on R.
0.4 91.7 Crossing Lockatong Creek. "The Lockatong formation takes its name from an excellent section exposed along this creek two to four miles upstream. The hill northwest of the river road is capped by the basal beds of the Lockatong which there overlie the more easily eroded upper part of the Stockton formation" (Johnson and McLaughlin, 1957, p. 61). According to Van Houten (1969, p. 333, his mileage 20.1): "Quarry in Stockton Arkose high on the west bank of the river."

0.4 92.1 Quarry Road on R (to Rosemont).
0.7 92.8 Raven Rock quarry on R. This was the place from which a "fabulous discovery" of uranium was reported, but was debunked by Johnson and McLaughlin. This quarry "is of chief interest in affording good exposure of the light-gray to almost white (sic) arkosic (sic) sandstone that has been used in the construction of three churches in Trenton within the last decade, as well as many other structures in prior years. Here there is no conglomerate and the sandstone is uniform in texture, occurring in gray (sic) and reddish-brown beds ranging up to 15 feet thick" (Johnson and McLaughlin, 1957, p. 62).

According to Van Houten (1969, p. 333, his mileage 21.3): "Raven Rock. Old quarry to E in massive fine-grained arkose of the Raven Rock Member 300 ft thick, just S of road to Rosemont."

0.3 93.1 Co. 651 on R. Reddish-brown sandy mudstones and sandstones near here are in the uppermost Stockton (Van Houten, 1969, p. 333, his mile 21.6).
0.5 93.6 Start outcrop on R at Byram. According to Johnson and McLaughlin (1957, p. 63) at the E end of the former Byram-Point Pleasant bridge (destroyed during the August 1955 flood), massive argillite beds of the basal Lockatong are exposed (plus in the quarry just to the N). "The rock here is hard and breaks with a conchoidal fracture like dense flint."
0.2 93.8 Lockatong Formation exposed on R.
0.2 94.0 High cliff on R.; exposures continuous. According to Van Houten (1969, p. 333, his mile 22.9 and Stop 2): "Roadcut in Byram diabase and metamorphosed Lockatong." The Lockatong here is about 1,000 to 1,500 ft above the base; hornfels is present where the Lockatong is in contact with the igneous rock (both at top and bottom).

0.6 94.6 Pull over on R for Stop 4.

STOP 4 - Lockatong Formation. [UTM Coordinates: 495.0E / 4475.8N, Lumberville quadrangle.]

We will try to follow what Van Houten described from his Stop 2, 1969 GSA trip, p. 33, mile 22.9 to 23.1 (Figure 15):

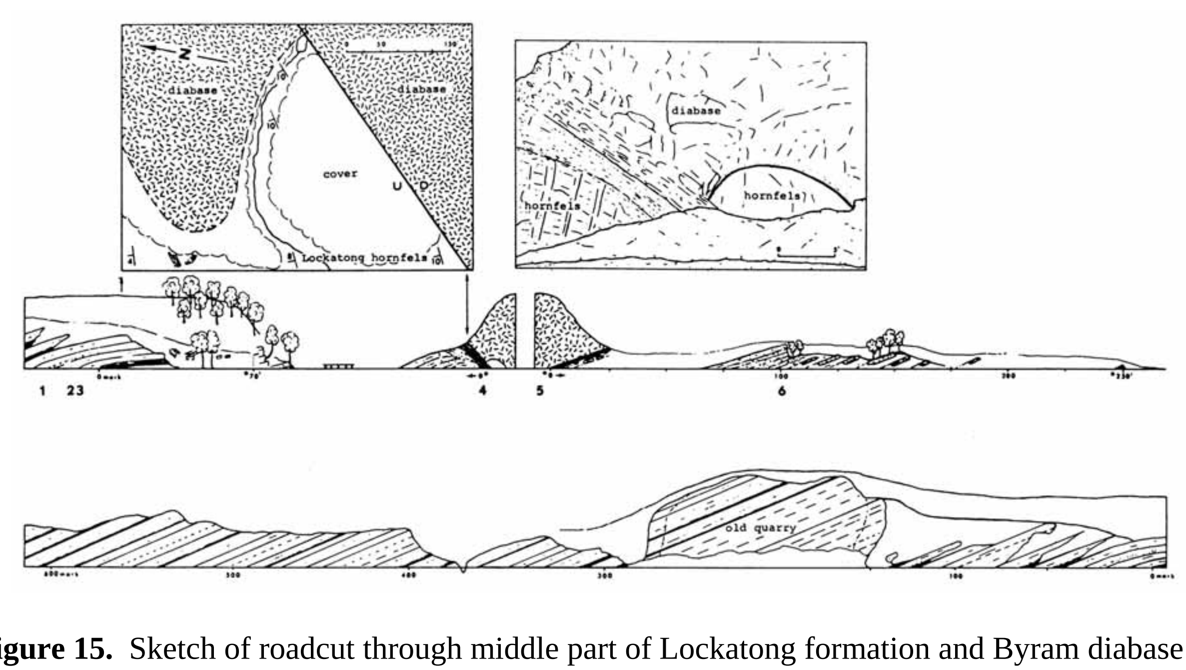

Figure 15. Sketch of roadcut through middle part of Lockatong formation and Byram diabase sill exposed along Route 29, in Byram, New Jersey. As described in the text as Stop 4, the lower section shows the base of sedimentary cycles as heavy lines. Analcime-rich chemical cycles occur between the 450' and 550' marks and cancrinite occurs as much as 425 feet above contact with Byram diabase sill (upper section). (Van Houten, 1980, figure 8, p. 272.)

Items:

1. Vague cyclic pattern of major ledges of albite-biotite hornfels; Nepheline (sic) occurs about 100 ft below sill.

2. Lower contact of chilled border of diabase with sheared, weathered Lockatong pelitic hornfels.

3. Coarse-grained diabase, extensively fractured. Joint minerals include calcite, epidote, prehnite, tourmaline and amphibole. Conspicuous lineations expressed in concentration of joint minerals have (sic) no apparent relation (sic) to compositional layering in the diabase.

4. Complex upper contact (enlargement), essentually undisturbed along curved contact; faulted (sic) and sheared diabase and hornfels on north side. Nepheline, cancrinite, pyroxene and amphibole presesnt in both blocks of Locaktong albite-biotite hornfels.

5. Relation (sic) of 70-foot sequence from fault to outcrops north of creek is obscure. Isolated exposures and sheared zones at roadside topographically below position of northern lobe of diabase (see sketch map).

6. O marks beginning of undisturbed, continuous sequence of Lockatong Formation, estimated to be about 70 feet above the faulted contact with diabase. Nepheline absent above the 11-foot mark (81 ft above diabase); cancrinite and albite diminish and analcime and thomsonite increase out to the 370-foot mark. Analcime and albite present above this level. Analcime and thomsonite also occur as joint minerals.

23.1 7. Metal disc at 10-foot mark 6 feet above road records level of flood water in September, 1955.

"Conspicuous white sprays of cancrinite, albite and calcite at 21-foot mark apparently developed from analcime dolomite sprays as seen at Stop 3."

We will also try to find some of what Paul Olsen (1986) has named Van Houten cycles (lake deposits made during a change from deep water to shallow water (or even no water) and back to deep water again. Such changes characterize lakes in closed drainage basins. The water-level fluctuations are controlled by climatic changes. Studies of the cyclicity by Van Houten (1962, 1964) and Olsen (1984, 1986, and continuing from the Newark-basin cored borings) have indicated cycles having periods coinciding with the climatic cycles computed by Milankovitch based on variations in the Earth's orbital elements. The finding of such Milankovitch-type cycles in rocks as old as Late Triassic-Early Jurassic demonstrates that the computer-modelling gurus who claimed that the Milankovitch periodicities break down within a few million years have got their mathematics all wrong.

0.8 95.4 More exposed Lockatong Formation.
0.3 95.7 Tumble Falls Road on R.
0.3 96.0 High cliff on R; exposures continuous.

0.1 96.1 Warsaw Road on R with red-colored Passaic Formation in cliffs (Figure 16). This is stop 4 of the 1980 NYSGA trip (a repeat of his 1969 stop), which Van Houten (1969, p. 335-336) described as follows (his mile 25.5):

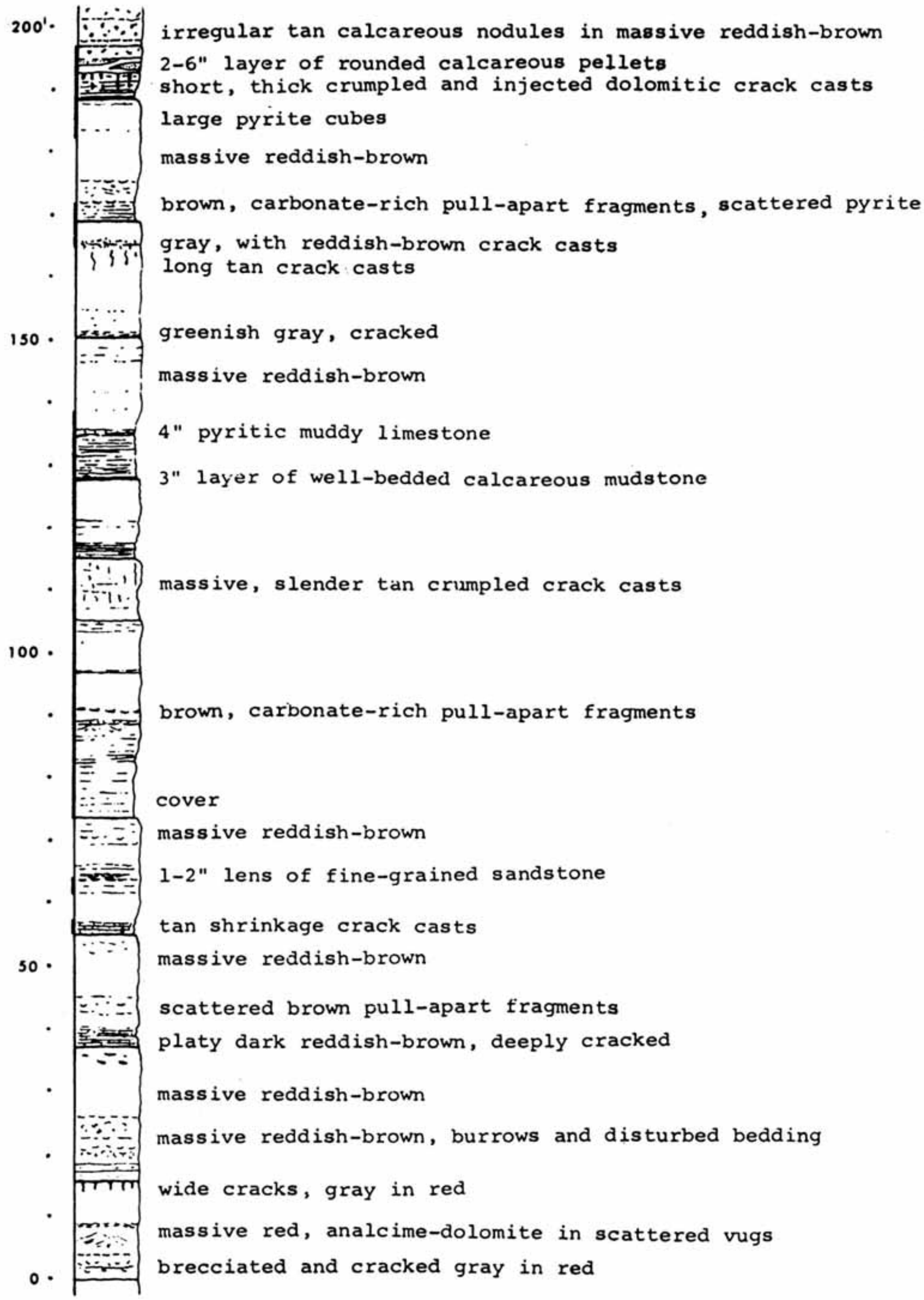

Figure 16. Columnar section from Stop 5 showing upper 75 feet (20m) of lowest reddish-brown unit in Passaic (nee Brunswick) formation and overlying lowest gray unit C exposed along route 29, 5 miles south of Frenchtown, New Jersey. (Van Houten, 1980, figure 7, p. 271.)

"Ravine and side road to E in middle of lowest reddish-brown unit assigned to Brunswick [now Passaic--JES] Formation (about 200 ft above base of formation). //(p.336) Traverse 0.2 mile long to lowest Gray unit C about 300 ft above the base (fig. 18).

"Massive reddish-brown deposits commonly burrowed and characterized by repeated shrinkage-cracking of two kinds of layers:

1. very thin greenish-gray beds; locally wafers are scattered through reddish-brown aragillite.

2. layers of brown-weathering dolomite-rich mudstone 1/2 to 1 1/2 inches thick, commonly as pullaparts; locally fragments are widely dispersed.

25.7 "Reddish-brown argillite above gray unit C contains scattered tiny flecks of pyrite and scattered brown-weathering irregular dolomite nodules as much as 1 1/2 inches long. Many of them contain irregular pataches of sparry calcite or are small septarian nodules with cracks filled with calcite. Some are crudely concretionary and may be of algal origin.

"Gray unit C is the lowest of eight recurring gray units centered at about 400-foot intervals. McLaughlin traced Unit C northeast to its end in the Hammer Creek Conglomerate, and 16 miles southwestward where it thins and ends in reddish-brown mudstone. The unit consists of black, platy carbonate-rich beds with abundant pyrite, below massive gray argillite commonly with long, slender crumpled crack casts. The platy part contains two very distinctive deposits:

1. black mudstone layers about 1 - 1 1/2 inches thick, with wide complexly crumpled (sic) and injected shrinkage crack (sic) casts of brown-weathering muddy dolomite and minor calcite.

2. Long lenses of pyritic pellet dolomite 6 - 12 inches thick, with silty round (sic) and flattened burrow casts and thin aracuate calcitic skeletal debris (ostracodes?) in the upper part. The intraclasts are 1/16- to 1/4-inch mudstone and massively (sic) and crudely concretionary dolomitic pellets, some of which have (sic) internal shrinkage cracks filled with sparry calcite."

0.8 96.9 No more exposures along road.
0.6 97.5 Kingwood Station-Barbertown Road on R.
0.8 98.3 MP 32 on R.
1.0 99.3 MP 33 on R.
0.3 99.6 Leave Lumberville quadrangle, enter Frenchtown quadrangle.
0.9 100.5 Frenchtown; end NJ 29; West Washington Street.
0.3 100.8 Bridge over.
0.2 101.0 T intersection, Bridge St.; turn L; then take first R into Harrison Street (Co. 619 N).
1.0 102.0 Passaic red shaly siltstones exposed on R.
0.5 102.5 End of exposures.
0.1 102.6 Driveout on R by hot-dog trailer for Stop 5.

STOP 5 - Passaic Formation (formerly Brunswick Redbeds - only the name has changed, not the color!) [UTM Coordinates: 494.0E / 4488.5N, Frenchtown quadrangle.]

Here, next to the dilapidated hot dog van, note red siltstones, very fine sandstones, and shale. The bedding surfaces are oriented N50°E, 07°NW and display mudcracks, raindrop-impact pits, tiny ripples, and possible dinosaur tracks. Joints are spaced about a meter apart and are oriented N58°E, 75°NW. Grab a hot dog, if you dare!

0.0 102.6 Reboard vans; turn R and continue on Co. 619.
0.8 103.4 Passing MP 2 on Co. 619 on R.
0.2 103.6 Passing Stamets Road on R.
0.2 103.8 Passing paper mill on L.
0.4 104.2 Junction with Co. 519 on R; entering Milford.
0.1 104.3 Traffic light at Milford Post Office. Turn L and cross canal.
0.2 104.5 Turn R into Church St; in front of church, turn L.
0.1 104.6 Turn R into Spring Garden Street. Co. 627 follows RR tracks.
0.7 105.3 Continuous exposures of Passaic Formation on R; narrow road, be careful.
0.6 105.9 Passing MP 1 on Co 627 on R.
0.1 106.0 Spring Garden Road goes uphill on R; stay on Co. 627.
0.1 106.1 Leave Frenchtown quadrangle, enter Riegelsville quadrangle.
0.3 106.4 Pull over on R for Stop 6.

STOP 6 - Basin-marginal rudites in Passaic Formation, S end of Gravel Hill. [UTM Coordinates: 488.5 E / 4491.5N, Riegelsville quadrangle.]

Those of you who have been to Oakland, New Jersey, on our Palisades Newark Basin trip, will find this exposure looks somewhat familiar. Discrete layers containing rounded boulders of Paleozoic rocks, most of which are quartzites, but with the light-colored ones carbonates, are interbedded with layers composed of sand-size sediment (Figure 17). In some of the fine layers are scattered rounded boulders. According to Bradford Willard (1956), the limestones are fossiliferous Decker Limestone (Silurian?) and the quartzites are from the Green Pond Formation (Lower Silurian). This location is about 1 mile SE of the basin-marginal fault. [Computer batteries gave out here and we had to resort to writing field notes by hand with a sharp pin and some blood.] As high stratigraphically as these rocks are, JES would have you believe that they do not extend high enough to reach the Orange Mountain Basalt (known in scattered synclines both to NE and SW; See Figure 6.).

This was Stop 6 (Milepost 37) on the 1969 GSA trip. Quoting again from Van Houten's guidebook (1969, p. 337, his mile 35.9): "Southward projecting (sic) lobe of quartzite-rich Hammer Creek Conglomerate about 100 ft above its base. Dip generally 10-15 NW. Fault in ravine between the two major outcrops.

"More clasts are less than 3 inches in diameter, a few are 5 inches across; the largest are 9 inches long. The detritus is arranged in a succession of fining-upwards (sic) sequences (fig. 20) scoured at the base and gradational upwards (fig. 21B, C). The upper poorly-sorted (sic) mudstone is locally cross-bedded (sic) in SE outcrops, but essentially unbedded (sic) in NW outcrops. Calcareous nodules and patches (sic) in upper part of each unit are suggestive of cornstone in fossil soils of the upper Old Red Sandstone (Burgess, 1961).

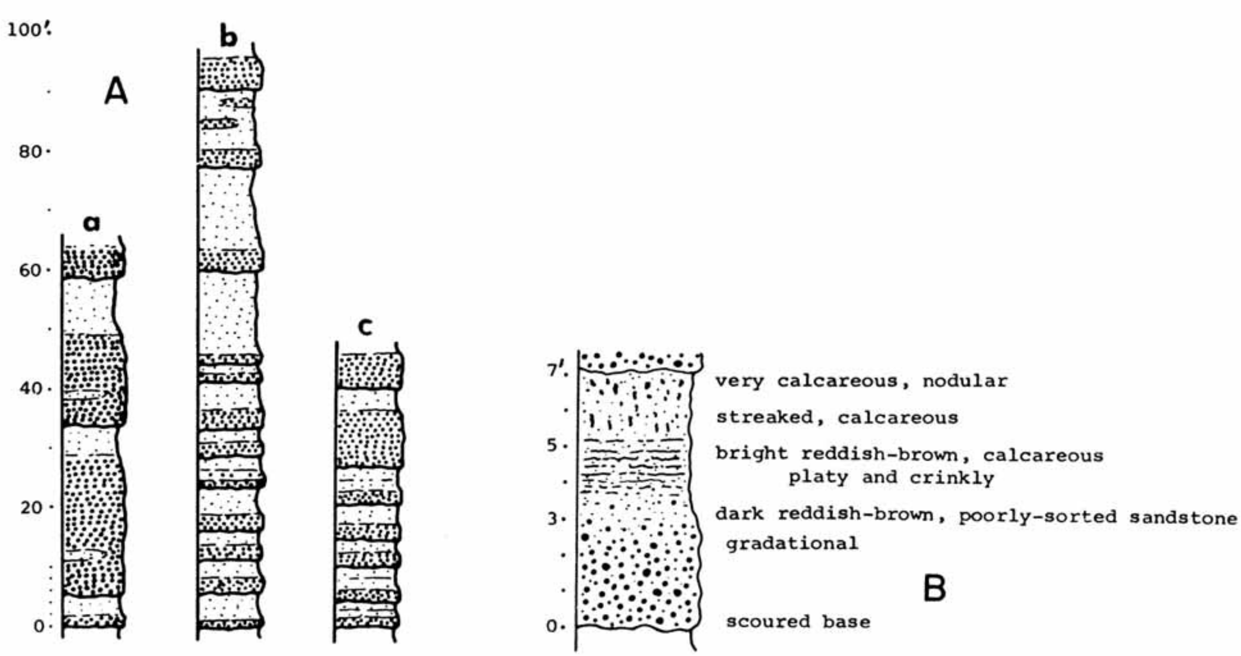

Figure 17. A. Sections from Stop 6 of lenticular, upward-fining sequences in Hammer Creek Conglomerate as exposed along Pebble Bluffs, route 67, about 2 miles west of Milford, New Jersey. Section a. is drawn roughly 0.5 miles northwest of c.

B. Model of upward-fining conglomerate-sandstone sequence. Note capping calcrete paleosol suggesting episode of non-deposition during warm, arid climates. (Van Houten, 1980, figure 5, p. 269.)

"This border facies exhibits many of the characteristic features of alluvial fan (sic) deposits which differ markedly from regionally extensive, rather well-sorted and rounded (sic) conglomerates of many molasse sequences. Some of its significant features are:

1. Located less than five miles from the border fault.
2. Source area probably less that 25 miles away.
3. Abundant matrix and associated poorly-sorted (sic) sandstone indicating rapid deposition and little by-passing (sic).
4. Conspicuous lensing (sic) and channeling (sic).
5. Rapid gradation into a more distal (sic), finer-grained facies."

0.0 106.4 Continue ahead on Co. 627.
[Here we depart from the route we followed on the pre-trip excursion and follow Van Houten's (1969) trip. We head for I-78 by a shorter route that goes along the margin of the Newark basin. Excuse us if we muddle up the mileages.]

1.3 107.7 Turn R on Phillips Road. Gilbert Generating Station in valley to south. Steep cliff on far S side of river shows patterned sequence of upper Brunswick deposits. Uppermost beds are gray hornfels beneath Coffman Hill diabase.

0.9 108.6 T-intersection at Church Road (Amsterdam), turn R. At Holland Presbyterian Church, about 1 mi SW of this intersection, Johnson and McLaughlin wrote (1957, p. 66-67): "Massive beds of limestone conglomerate, dipping 32° N.W., are exposed just behind the church and immediately south of the road to Amsterdam. Only a few hundred feet farther north, the // (start p.67) Kittatinny limestone could formerly be seen, dipping 48° S.E., and a little quartzite float higher on the hill suggested the probable occurrence of a narrow band of the Hardyston quartzite between the limestone and the Proterozoic gneiss which forms the backbone of Musconetcong Mountain. Structural relations (sic) are difficult to decipher because of overburden, but are believed to be as represented below." (We have made their sketch into our Figure 18.)

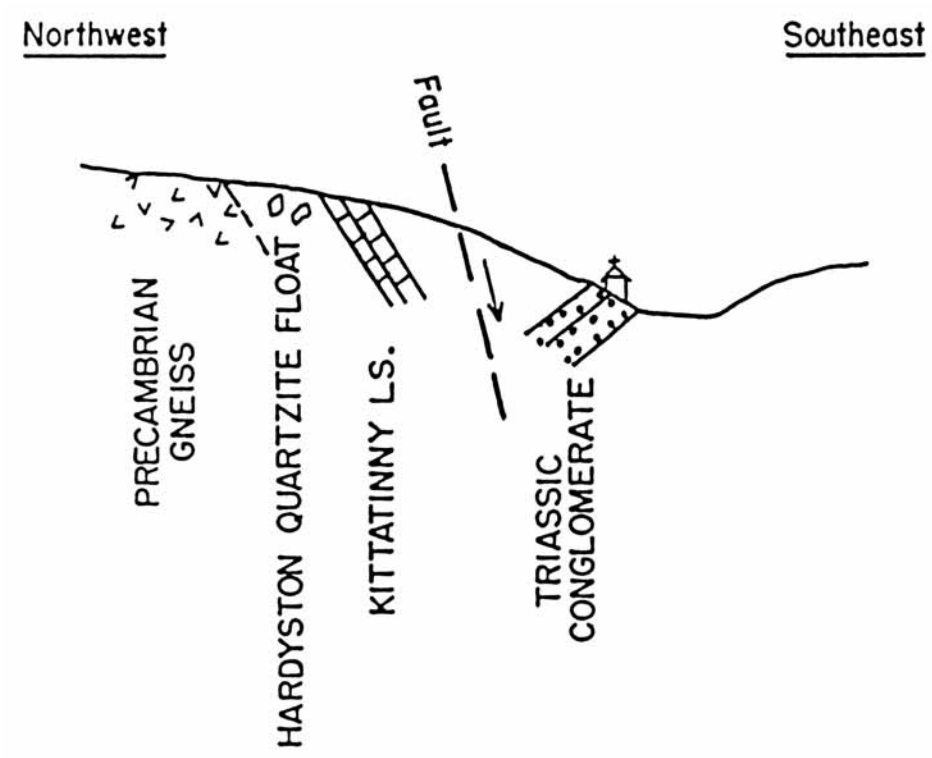

Figure 18. Sketch profile of geologic relationships along Newark basin marginal fault north of Holland Presbyterian Church. (Johnson and McLaughlin, 1957, p. 37.)

The SW end of Musconetcong Mountain ends at the Delaware River; the Proterozoic rocks of this mountain probably disappear from the landscape by striking obliquely against the basin-marginal fault.

Church Road follows along the basin-marginal fault marking the NW border of the Newark basin. Proterozoic rocks form Musconetcong Mt. to N. A sliver of Lower Paleozoic rocks has been faulted against the Proterozoic gneiss and overlapped by the Hammer Creek Conglomerate.

0.4 109.0 Quarry in Hammer Creek Conglomerate on R. Paleozoic (mainly Silurian) quartzite clasts have been extensively fractured by crushing in fault zone.
0.9 109.9 Powerline crossing overhead.
0.2 110.1 Leave Rieglesville quadrangle; re-enter Frenchtown quadrangle.
0.4 110.5 T intersection at Spring Mills. Turn R, then immediately L on Co. 519. The rocks here are "normal" Passaic redbeds, not the usual basin-marginal rudites.
1.3 111.8 Y-shaped junction; take L fork toward Little York. For the next 0.4 mile (according to Van Houten, 1969), the road crosses "older drift."
0.7 112.5 T intersection; turn L toward Little York.
0.3 112.8 Little York. Patch of quartzite-rich Hammer Creek Conglomerate faulted against a fault-sliver (sic) of Cambrian limestone. Turn R on road to Pattenburg.

1.4 114.2 This road follows a major area of quartzite-rich conglomerate that interfingers to E and SE with all the formations of the Newark Group (here, from top down, Passaic, Lockatong, and Stockton), which have been folded so that they strike toward the basin-marginal fault. This change from coarse basin-marginal rudites close to the basin-marginal fault to finer sediments farther away from the fault throughout such a large stratigraphic range indicates that during Late Triassic and Early Jurassic time, the block NW of the basin-marginal fault was repeatedly elevated.

1.0 115.2 Intersection, The Hickory. Leave Frenchtown Quadrangle, enter Bloomsbury quadrangle. Cross Rt. 579 on border fault. Road follows sliver of Paleozoic rocks in basin-marginal fault zone.

1.5 116.7 Pattenburg, on northern edge of Hammer Creek Conglomerate lying on Cambro-Ordovician basement rocks that are faulted against gneisses of the Highlands. Pattenburg is at the SE end of the famous tunnel on the Lehigh Railroad through Musconetcong Mountain where the Proterozoic gneisses were found to have been overthrust above the Paleozoic rocks. Where I-78, which we shall join shortly, crosses Musconetcong Mountain, it passes directly above the tunnel (497.4 E / 4499.6 UTM, Bloomsbury quadrangle). Cross Mulhockaway Creek and continue NE toward US Route 22.

0.9 117.6 Leave Bloomsbury quadrangle, enter High Bridge quadrangle.
0.1 117.7 Take ramp on R at Interchante 11 to enter I-78 E.
1.5 119.2 Passing Exit 12 (NJ 173, Jutland, Norton) on R.
0.8 120.0 MP 14 on R.
0.5 120.6 Rocks exposed on R; what are they? Taconic green slates? We couldn't tell at 55 mph.
0.5 121.1 MP 15 on R.
1.2 122.3 Passing Exit 15 on R (NJ 173, Clinton, Pittstown). Interstate 78E traverses contact of Paleozoic rocks and overlapping Hammer Creek Conglomerate. (Note: the Hammer Creek Conglomerater referred to is at the base of the Newark strata. If its lateral equivalent could be worked out in detail, JES thinks it would be found to be the base of the Stockton Formation.)

1.0 123.3 Passing Exit 16 on R (NJ 31 to Washington).
0.3 123.6 Passing Exit 17 on R (NJ 31 S; Flemington and Trenton).

0.7 124.3 According to Van Houten (1969, p. 338, his mileage 55.6) the rocks here are: "Complexly faulted Cambro-Ordovician strata and Proterozoic gneisses that project S into Newark Basin are bounded on the E by the Flemington Fault."

0.1 124.4 Passing Exit 18 on R (US Route 22 E (Annandale and Round Valley, where New Jersey built a reservoir inside the C-shaped Cushetunk Mountain).
0.7 125.1 MP 19 on R.
0.9 126.0 According to Van Houten (1969, p. 338, his mileage 57.3) I-78 here crosses the "NE end of the Flemington Fault at junction with border fault. Proterozoic gneiss to S is faulted against a syncline in the Cushetunk Mt. diabase which encloses the Round Valley reservoir." Van Houten's use of "diabase" implies an intrusive, the interpretation accepted by geologists in New Jersey. JES stirred up a hornet's nest when he suggested that this mountain was not a ring dike, as claimed by the New Jersey Geological Survey and consultants, but a remnant of an anticlinal fold in the Second Watchung (now the Preakness Basalt), and thus an extrusive sheet (fig. ref to JES map).

1.1 127.1 MP 21 on R; reddish-brown soil indicates we are back in the Newark basin again; probably in the Passaic Formation. The ridge on the R is Cushetunk Mountain itself.
3.8 130.9 Passing Exit 21 on R (NJ 24 to Oldwick, White House, and Co. 523 to Co. 517). Syncline in New Germantown flow (400 feet +/- thick) forms low hills a mile N.
1.2 132.1 MP 26 on R.
1.0 133.1 Passing Exit 26 on R Co. 523 spur (Lamington, North Branch) and MP 27 on R.
2.0 135.1 MP 29 on R.
1.0 136.1 Leave I-78 at Exit 29 on R for I-287 (Morristown, to US Route 202, US Route 206, and I-80).
0.6 136.7 Bear L for ramp on L to Morristown.
0.3 137.0 The wooded ridge ahead is underlain by the Preakness (formerly Second Watchung) Basalt striking NW-SE and dipping NE on the NE limb of the Somerville anticline. The underlying Orange Mountain Basalt (formerly First Watchung) ends abruptly about a half mile to the SE. JES thinks this abrupt ending is caused by the cutting off of the outcrop belt by the Hopewell fault.

0.3 137.3 On I-287 northbound.
0.4 137.7 Passing Exit 18A on R (US Route 202 and US Route 206 S (Plukemin).
0.1 137.8 MP 22 on R.
0.3 138.1 Passing Exit 18B on R (to Bedminister and Netcong).
0.4 138.8 MP 23 on R.
0.4 139.2 I-287 turns E and crosses 2nd Watchung Mountain. Preakness Basalt in cuts, both sides of I-287.
0.5 139.7 Preakness Basalt in cuts on R.
0.1 139.8 MP 24 on R.
0.3 140.1 More Preakness Basalt in cuts on R.
0.2 140.3 More Preakness Basalt in cuts on R.
0.5 140.6 Entering Bernardsville Township.
1.0 141.6 MP 26 on R.
0.3 141.9 Passing exit on R for Mt. Airy Rd. (Liberty Corner).

From Van Houten, 1969 (p. 338, his mile 71.4): "At Moggy Hollow (crossing Mine Brook Road) road heads NE between the recurved 2nd Watchung Mt. to the NW and the 3rd (Long Hill) Watchung to the E and SE. "Glacial Lake Passaic dammed between the Highlands and the Watchung Mts. drained southwestward through Moggy Hollow to the North Branch of the Raritan River when outlets to the northeast were blocked by the ice sheet."

0.3 142.2 Passing exit on R for Mt. Airy Rd (Bernardsville).
0.4 142.6 MP 27 on R.
2.4 145.0 MP 29 on R.
0.4 145.4 Passing Exit 26A on R (N. Maple Avenue, Basking Ridge).
0.2 145.6 Passing Exit 26B on R (N. Maple Avenue, Morristown).
2.0 147.6 MP 32 on R.
0.5 148.1 Take ramp on R for Rest Area. [Pit Stop 15 min.]

0.6 148.7 Back on I-287 N; MP 33 on R.
0.9 149.6 Morris Township sign just before ramp on R for Exit 29, Harter Road.
0.1 149.7 MP 34 on R.

Somewhere in here we cross the Passaic River, and can include the following from Van Houten (1969, p. 338, his mile 76.4): "IS 287 crosses Passaic River. In its last stage Glacial Lake Passaic was drained northeastward through gaps at Little Falls and Paterson by the Passaic River system. A small lake was left in the area of the Great Swamp. The border fault 1,500 ft to NW continues as the remarkably straight Ramapo Fault for about 50 miles to the NE end of the basin."

1.0 150.7 MP 35 on R. From Van Houten (1969, p. 338, his mile 77.4) "Narrow gap between border fault and west end of anticlinal outlier of 3rd Watchung Flow [now Hook Mountain Basalt--JES] (New Vernon Ridge)."
0.5 151.2 Passing Exit 35 (nee 24) on R; NJ 124 (South Street, Madison Avenue).
0.5 151.7 MP 36 on R. From Van Houten (1969, p. 338, his mile 78.4): "Patch of Hammer Creek Conglomerate in low hill to E."
0.2 151.9 Passing Exit 36A on R, Co. 510 E (Washington Headquarters - he sure got around, didn't he?).

0.4 152.3 Passing Exit 36B on R, Co. 510 W (Lafayette Ave.)
0.2 152.5 Entering Morris Township (again; when did we leave it?).
0.6 153.1 Entering Hanover Township.
0.4 153.5 Passing Exit 37 on R, NJ 24 E (Springfield).
0.1 153.6 MP 38 on R.
0.3 153.9 Entry from Van Houten (1969, p. 338, his mile 80.6): "Northern horn of New Vernon anticline in 3rd Watchung [now Hook Mountain Basalt--JES] flow."
1.1 155.0 Passing Exit 39 (nee 35) on R, NJ 10 (Dover, Whippany).
1.4 156.4 Passing Exit 40 on R, Co. 511 (Parsippany, Whippany).
1.1 157.5 Leave I-287 via ramp on R for Exit 41A (I-80, US Route 46 E).
0.1 157.6 Keep L at split for US Route 46; head for I-80 E.
0.5 158.1 Join I-80 E service road.

1.0 159.1 Passing Exit 45 on R (Whippany, Lake Hiawatha).
0.7 159.8 Take Exit 47A on R (I-280 E to NJ Turnpike).
0.4 160.2 On I-280 eastbound.
0.5 160.7 MP 1 on R.
1.0 161.7 MP 22 on R; crossing low, flat area.
1.3 163.0 Entering Roseland Boro; plus crossed a river.
0.4 163.4 Passing Exit 4A on R, Eisenhower Parkway (Chatham).
0.2 163.6 Passing Exit 4B on R, Eisenhower Parkway (local only).
0.9 164.5 Passing Exit 5A on R, Co. 527 S (Livingston).
0.2 164.7 Passing Exit 5B on R, Co. 527 N (The Caldwells).
1.1 165.8 Passing Exit 6 on R (Laurel Avenue).
0.8 166.6 Cuts in Preakness (nee 2nd Watchung) Basalt on both sides.
0.4 167.0 End basalt cuts.
0.3 167.3 Passing Exit 7 on R (Pi Valley, Milburn, Verona).
0.4 167.7 Cuts in basalt.
0.2 167.9 Passing Exit 8A on R, Co. 577 S (Prospect Avenue, West Orange).
0.1 168.0 Passing Exit 8B on R, Co. 577 N.
0.5 168.5 More deep cuts in Orange Mountain Basalt.
0.5 169.0 Passaic Formation redbeds in I-280 cuts.
0.2 169.2 Passing Exit 9 on R, Mt. Pleasant Ave. (W. Orange, Montclair); redbeds at top of Passaic Formation in ramp cuts.
1.0 170.2 Passing Exit 11 on R, Center Street (Orange and S. Orange).
0.5 170.7 Passing exit to Harrison Street, Clinton Street (E. Orange).
0.2 170.9 Entering E. Orange.
0.5 171.4 Passing Exit for Oraton Parkway on R (to GSP).
0.6 172.0 Passaic Formation redbeds in cut at L; dip W.
0.7 172.7 Passing Exit 13 (3 left lanes) for Newark. Bear R to NJ Turnpike.
0.9 173.6 Passing Exit 14 on R (King Blvd.); MP 14.
0.6 174.2 Start drawbridge.
0.1 174.3 End drawbridge; just beyond, on R, Exit 16 (Harrison).
1.9 176.2 Passing Exit 17 A on R, Co. 508 (Jersey City). Take ramp on L for NJ Turnpike.
0.4 176.6 Passing Exit 17 B on R, Co. 508 (Kearny).
0.4 177.0 Toll gate at entrance to NJ Turnpike.
0.1 177.1 Exit 16 E for Lincoln Tunnel on R.

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TABLES

Table 01 - GEOLOGIC TIME CHART

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

ERA Periods (Epochs)	Years (Ma)	Selected Major Events
CENOZOIC		
(Holocene)	0.1	Rising sea forms Hudson Estuary, Long Island Sound, and other bays. Barrier islands form and migrate.
(Pleistocene)	1.6	Melting of last glaciers forms large lakes. Drainage from Great Lakes overflows into Hudson Valley. Dam at The Narrows suddenly breached and flood waters erode Hudson shelf valley. Repeated continental glaciation with five? glaciers flowing from NW and NE form moraine ridges on Long Island.
(Pliocene)	6.2	Regional uplift, tilting and erosion of coastal-plain strata; sea level drops. Depression eroded that later becomes Long Island Sound.
(Miocene)	26.2	Fans spread E and SE from Appalachians and push back sea. Last widespread marine unit in coastal-plain strata.
MESOZOIC	66.5	
(Cretaceous)		
	96	Passive eastern margin of North American plate subsides and sediments (the coastal-plain strata) accumulate.
	131	(Passive-margin sequence II).
(Jurassic)		Baltimore Canyon Trough forms and fills with 8,000 feet of pre-Cretaceous sediments.
		Atlantic Ocean starts to open. Newark basins deformed, arched, eroded.
	190	Continued filling of subsiding Newark basins and mafic igneous activity both extrusive and intrusive.
(Triassic)		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	**LAYER IIA[E] - TACONIC SEQUENCE**
Western shallow-water platform (L. Cambrian-M. Ordovician)	Eastern deep-water zone (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]	Stockbridge or Inwood Marbles (Ꞓ-Oh) Hartland Fm. (Ꞓ-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.
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Table 03 – Proposed new classification of the Pleistocene deposits of New York City and vicinity (Sanders and Merguerian, 1998, Table 2)

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

Table 04 - Stratigraphic Section of the Newark Supergroup Along the Delaware River, From Stockton Northward to Milford, New Jersey. (Johnson and McLaughlin, 1957.)

	"Triple Red"	Three red argillite units, separated by thick gray argillite units	131
		Thick-bedded, tough, black argillite	260
	"First Big Red"	Thick-bedded, tough, red argillite	100
LOCKATONG		Thick-bedded, tough, black argillite	262
	"First Thin Red"	Interbedded red and black argillite	58
		Thick-bedded, dark gray to black argillite	1,120
	Intrusive	Fine-grained diabase (sill)	210
		Black, hard argillite with interbeds of impure limestone	780
		Alternating black, purplish, and reddish, hard argillite, lowest 20 feet silty	305
		Red and brown sandstone, minor arkose	724
	Raven Rock	Massive, medium to coarse, white and gray arkose	293
STOCKTON		Red and gray fine sandstone and red shale, with minor arkose ..	787
	Cutalossa	Medium to coarse thick-bedded arkose with interbeds of red-brown fine sandstone	232
		Red and brown fine sandstone, red shale, and minor arkose ..	373
	Upper Prallsville	Thick-bedded, medium to coarse arkose with red sandstone interbeds	205
		Red and brown sandstone and red shale	136
STOCKTON	Lower Prallsville	Thick-bedded, coarse, white, gray and yellow arkose, with interbeds of fine red sandstone..	474
		Red fine sandstone (poorly exposed)	447
		Thick-bedded, medium-grain, gray arkose with minor conglomerate	224
	Solebury	Thick-bedded to massive coarse quartz-arkose conglomerate with interbedded arkose, red shale, and sandstone	387
		Arkose, red shale and sandstone, minor conglomerate	720
PALEOZOIC		Limestone	

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