HOFSTRA UNIVERSITY
014F FIELD GUIDEBOOK

GEOLOGY OF THE PALISADES AND NEWARK BASIN, NJ

18 October 2008

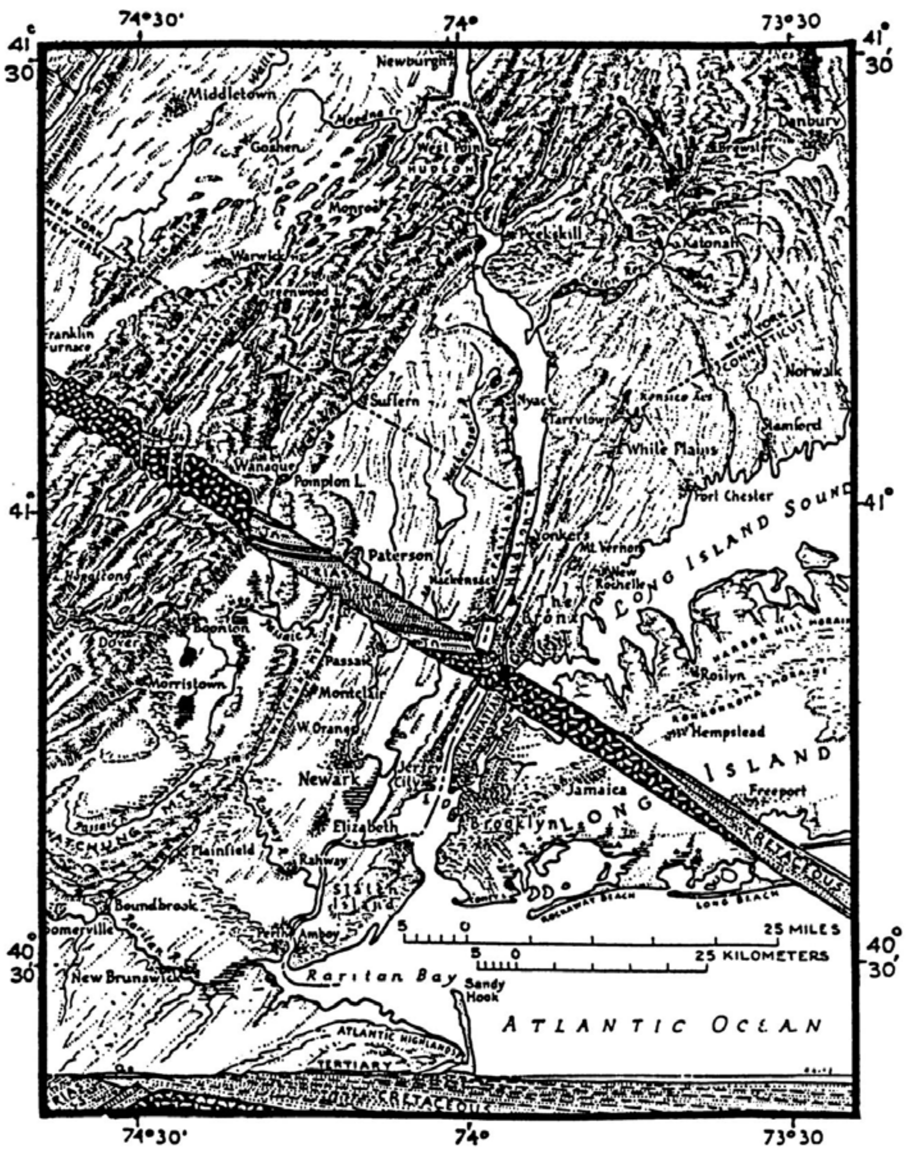


Figure 1 – Physiographic diagram of NY Metropolitan area with cutaway slice showing structure. (From E. Raisz.)

Field Trip Notes by:
Charles Merguerian

CONTENTS

HOFSTRA UNIVERSITY
014F FIELD GUIDEBOOK

GEOLOGY OF THE PALISADES AND NEWARK BASIN, NEW JERSEY

Fall 2008

INTRODUCTION

Today's field trip is intended to introduce the participants to the rocks (both sedimentary and igneous) that filled the Newark Basin (Figure 1, on cover), which subsided rapidly within the Appalachian highlands during the Late Triassic and Early Jurassic periods, approximately 200 million years ago. The eroded edges of these regionally NW-dipping basin-filling strata underlie the region lying between the Ramapo Fault of New Jersey and Rockland County, New York, on the NW, and the Hudson River between Stony Point, New York and Hoboken, New Jersey, on the SE. Many of the basin-filling strata are sedimentary rocks that tend to form lowlands. With them are four topographically prominent ridges that are underlain by mafic igneous rocks. From SE to NW, these are the Palisades sheet and the First-, Second-, and Third Watchung Mountains. The Palisades is an intrusive; the others are extrusive.

Table 1 is a geologic time scale with emphasis on the subdivisions shown on the bedrock maps herein, with estimates of numbers of years for their boundaries, and a list of some important local geologic events. It shows the general relationships of the units mentioned in our discussion. Table 2 summarizes the major local geologic units (stratigraphy) in terms of layers designated by Roman numerals.

Of particular interest today are the features found at the base of the Palisades sheet, the relationships between the extrusive sheets and the sedimentary strata, and the changes that can be observed within the sedimentary strata as one approaches the basin-marginal Ramapo fault.

We will drive westward from Hofstra across The Bronx to the George Washington Bridge (GWB). In order to get to the time when the rock units beneath us formed, we need to leap backward in time to the Proterozoic and Paleozoic eras. Midway across the GWB (Figure 2), we make a time leap forward from the Paleozoic into the Mesozoic, here represented by dominantly red-colored sedimentary rocks and intercalated mafic igneous rocks, which dip gently about 12° northwestward. The land surface is formed by the eroded edges of the strata, once formerly much more extensive than today, that filled the Newark Basin (Figure 3). The prominent cliff on the west bank of the Hudson River, the Palisades (Figure 4), is formed by the resistant edge of the igneous rock of the Palisades tabular intrusive sheet. (For many years, the

Palisades has been referred to by many as a sill [a concordant tabular pluton]. Because this sheet is locally discordant and concave upward in profile its proper technical name should be changed to lopolith.) The composition of this mafic rock is quite similar to the mafic rocks of the oceanic crust. Mafic rocks are named by their crystal size: gabbro is the coarse variety; dolerite, an intermediate variety with triangular interlocking crystals; and basalt, the fine variety.

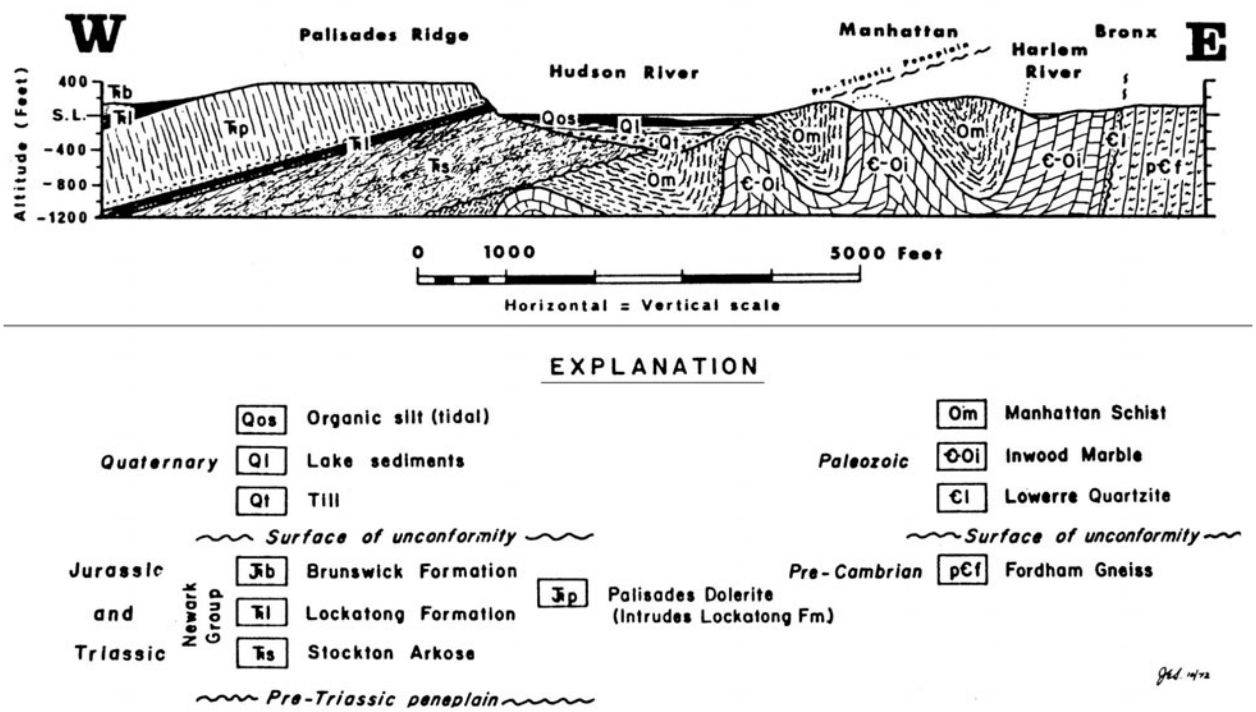


Figure 2. Profile-section across Hudson River at the George Washington Bridge. Topography from United States Geological Survey Central Park 7.5-minute quadrangle. (J. E. Sanders, 1974a, fig. 3, p. 11.)

Because of the prevailing northwest dip in the central part of the trip area (See cut-away slice on Figures 1 and 3.), as we drive northwestward during the course of today's trip, we will encounter successively younger strata among the Newark basin-filling strata. Geologists refer to traverses across the strike of strata starting with older strata and encountering successively younger strata as "traversing up section" (the "section" referring to the succession of strata, and the "up" to the progression from older strata to younger). By contrast, they refer to the reverse, that is, a traverse progressing from younger strata to older, as "traversing down section").

We will make our first stop at the western footing of the GWB to examine the contact relationships at the base of the Palisades intrusive sheet and study the formation it intruded, the Lockatong. From there, we will traverse westward past the upper contact of the sheet and drive past west-dipping sedimentary rocks of the Newark Supergroup on our way to stops to examine the three sheets of extrusive mafic igneous rock constituting the Orange Mountain Formation ("First Watchung basalt" of older usage), the Preakness Formation (former "Second Watchung basalt"), and Hook Mountain Formation (formerly "Third Watchung basalt"; each "basalt" named after one of the Watchung mountains that were numbered from east to west). These curvilinear mountain ridges are truncated on the northwest by the Ramapo fault (See Figures 1 and 3.) and we will end our day by examining the Newark Basin sequence in exposures close to the Ramapo fault.

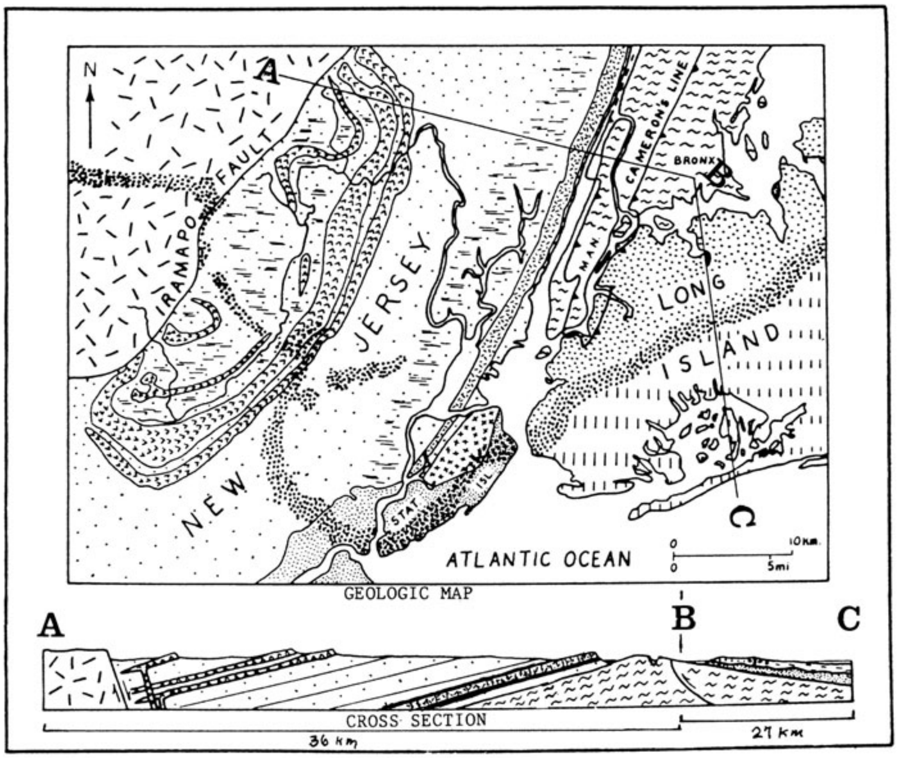


Figure 3. Sketch map and geologic profile-section, southeastern New York and adjacent New Jersey. Note lack of correspondence in scale between profile-section and map, with resulting expansion of the length of AB and shortening of line segment BC. (M. P. Wolff, M. J. Sichko, and R. S. Leibling, 1987, fig. 14.2A, p. 126.)

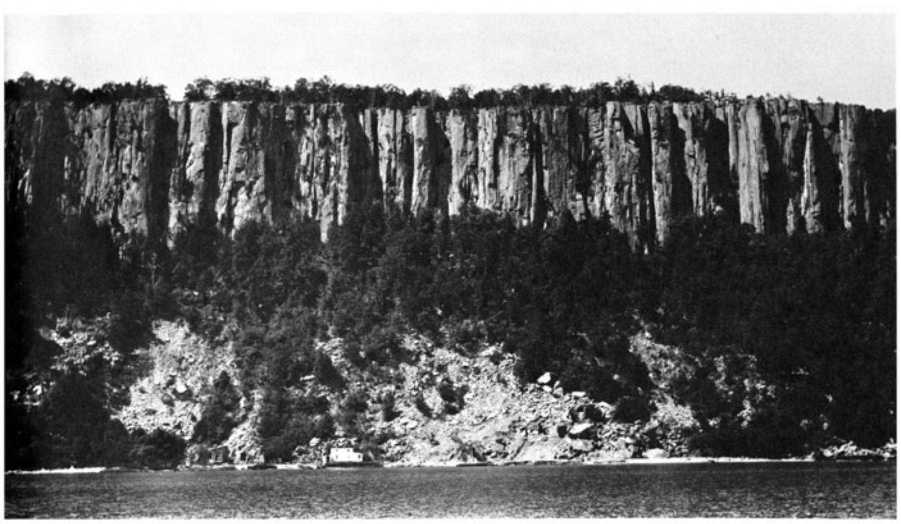


Figure 4. View of Palisades from above the Hudson River looking west. The nearly vertical columns of rock are bounded by steep joints that formed during contraction when the magma solidified to form the mafic igneous rock. (J. E. Sanders, 1981, fig. 6-26a, p. 165.)

GEOLOGIC BACKGROUND

Under this heading, we discuss the physiographic features, bedrock units, the glacial deposits, and the drainage history of our field-trip route.

PHYSIOGRAPHIC SETTING

The general physiographic name for the region we shall visit today is Newark Basin lowland. But, as we shall see, strictly speaking, the term lowland is appropriate for only parts of the region, for example the Hackensack Meadowlands ("the Swamp" according to New York's Governor Pataki), which lies close to sea level; and the Great Swamp south of Morristown, where most ground altitudes fall within the range of 150 to 250 ft. Much of the area underlain by Newark strata is enclosed on the NE and SE sides by the topographically prominent Palisades ridge. The region that includes the Great Swamp is bounded on the NW by the highlands province and is enclosed on the SW, SE, and NW by the three curvilinear ridges known as the Watchung Mountains (Figure 5).

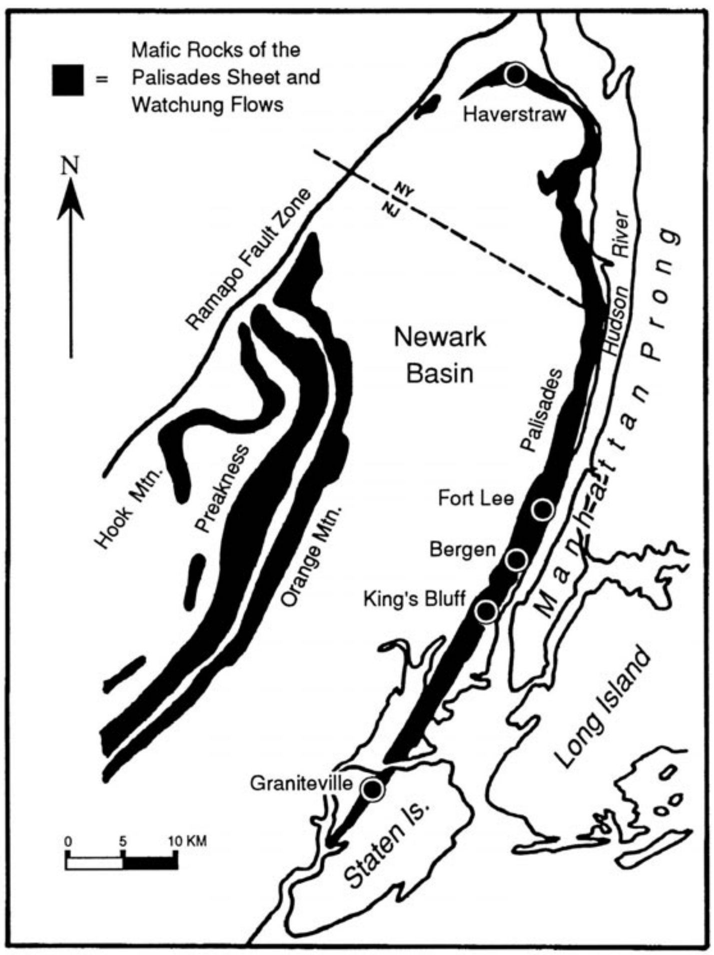


Figure 5. Index map showing the northern half of the Newark-Delaware Basin, the Palisades intrusive sheet, Watchung basalts, and place-names mentioned in the text. (After K. R. Walker, 1969, fig. 1, p. 6.)

We discuss these features from SE to NW, beginning with the Palisades Ridge. From Haverstraw, Rockland Co., NY, to Hoboken, Bergen Co., NJ, the Palisades ridge trends along the W shore of the Hudson River. But to both N and S, the ridge and river diverge. To the north, beyond Haverstraw, Rockland County, NY, the Palisades ridge curves around from its river-parallel NNE-SSW trend to a NW-SE trend. Thus, the ridge swings away from the river and strikes toward the Ramapo Range, the part of the Highlands province lying NW of the Newark Lowland.

To the S, the opposite situation exists. Instead of the ridge going away from the river, the river goes away from the ridge. At King's Bluff (alt. 180 ft) (above the Lincoln Tunnel), the NNE-SSW trend of the Palisades persists, but the Hudson River bends to the left about 20° and follows a course that is close to N-S. From Hoboken SSW to Bayonne is a triangular patch of low ground between the Palisades and Upper New York Bay. This low area is occupied by railroad yards, docks, and tank farms. At the gap used by the railroad leading to the Greenville Yards [UTM grid 577E - 4503N, Jersey City 7.5-minute quadrangle], the altitude of the crest of the Palisades is 50 to 60 ft. At Bergen Point, Bayonne, [UTM grid 573.8 E - 4499.6N, Elizabeth 7.5-min. quadrangle] on the N shore of the Kill van Kull (locally the boundary between Hudson Co., NJ and Richmond Co., NY), the altitude of the top of the top of the Palisades is between 30 and 40 ft.

Although the trend of the SSW decline in altitudes or the top of the Palisades ridge is accurate on a regional scale, a few notable exceptions exist. For example, the altitude of the highest point on the Palisades ridge, at High Tor, S of Haverstraw [UTM grid coordinates 586.76E - 4559.88N, Haverstraw 7.5-min. quadrangle] is more than 840 but less than 850 ft. From here to Hook Mountain State Park, the aspect is typical Palisades: columnar-jointed igneous rock. The altitude of the crest of Hook Mountain [UTM 590.8E - 4552.7N, Nyack 7.5-min. quadrangle] is more than 730 but less than 740 ft. From Hook Mountain State Park southward, especially around Nyack, to Sparkill Gap at Piermont [UTM 590.5E - 4542.6N Nyack 7.5-min. quadrangle], the ridge is an irregular low, wooded feature that does not display prominent jointed igneous rock (Figure 6). Farther south, the crestal altitudes of cliffs at Tallman Mountain State Park [Nyack 7.5-min. quadrangle] are 160 to 170 ft. Here, faults have dropped the igneous rock downward (Thompson, 1959). Just S of NJ-NY state line, 0.25 km NNW of the State Line Lookout [UTM 591.95E, 4538.15 N, Yonkers 7.5-min. quadrangle], the crestal altitude is 520 ft. Apart from the irregularity near Nyack, the Palisades ridge displays prominent rocky columns set apart by the columnar joints. At the Bergen/Hudson Co. Line, North Bergen, NJ, the crestal altitude is about 180 ft.

On Staten Island, NE of Travis Avenue and SE of Victory Boulevard [UTM 570E - 594.2N, Arthur Kill 7.5-min. quadrangle], the igneous rock of the Palisades lies at sea level; intertidal salt marshes overlap it. Just SW of the village of Travis, the SSW trend of the ridge carries it beneath the Arthur Kill and beyond into New Jersey. The SSW gradient of the crest of the ridge is about 800 feet in 40 miles, or 20 feet per mile.

The wide lowland between the Palisades Ridge and the First Watchung Mountain is underlain by topographically weak sandstones and mudstones. Local relief of up to 150 ft exists between the crests of ridges underlain by sandstone and adjacent lowlands underlain by mudstones. Large drumlins form the predominant landscape features.

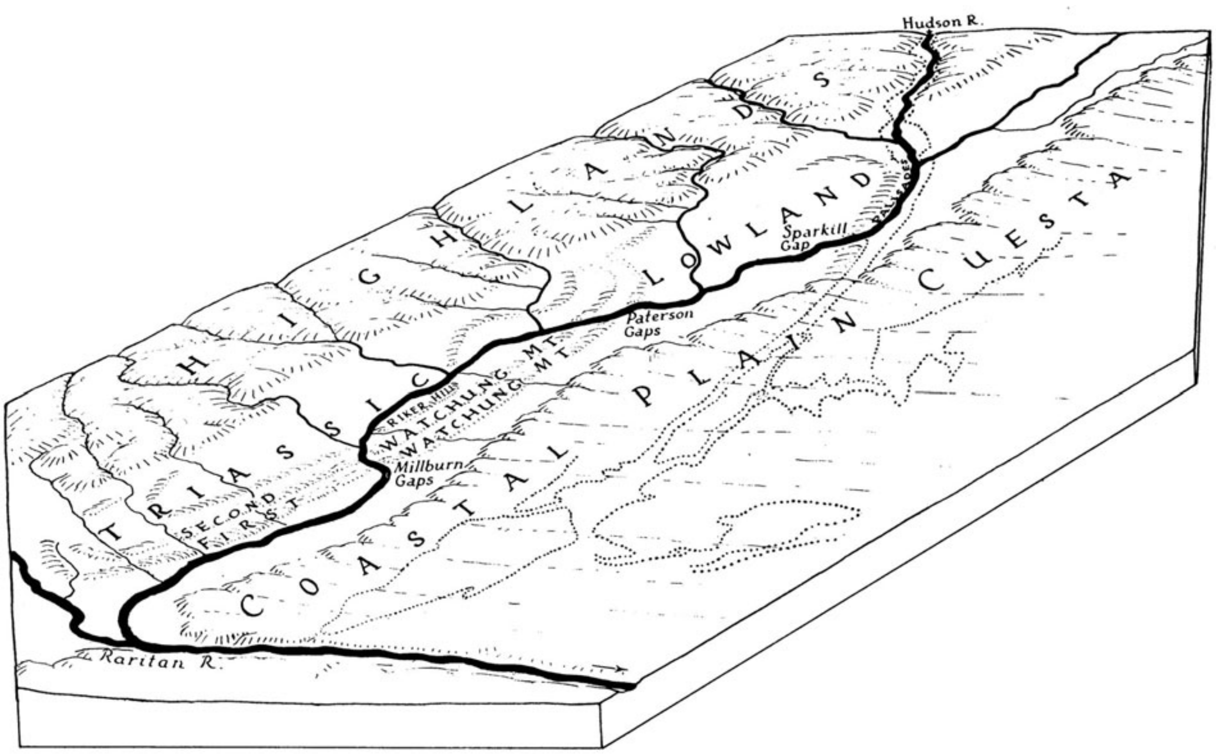


Figure 6. Block diagram showing how ancestral Hudson River, blocked by the inner coastal-plain cuesta, is inferred to have flowed southwestward through the Sparkill Gap, across the Watchung Ranges via the Paterson gaps and back again through the Millburn Gaps, to join the Raritan River near Somerville, New Jersey. The concept of superposition from the coastal-plain strata was part of Johnson's concept, but he dated this superposition as being from the Cretaceous strata. As is explained by Sanders (1974a), Johnson's concept of superposition might be valid, but if it happened at all, it would have had to have happened during the Pliocene episode of great regional uplift and would have been from the Miocene strata. The condition shown in this block diagram could have existed during the Pliocene Epoch. (Drawn by E. Raisz for D. W. Johnson, 1931.)

The Watchung Mountains are curvilinear ridges underlain by tilted sheets of mafic igneous rock that are topographically resistant. The curvature of the three Watchung ridges is generally concordant with that of the Palisades ridge. Altitudes along the crests of the First- and Second Watchungs lie in the 550- to 650-foot range. No regional gradient comparable to that of the Palisades is present. Geologically, the Watchungs differ from the Palisades in consisting not of tilted sheets of topographically resistant intrusive igneous rocks, as in the Palisades, but of tilted sheets of extrusive igneous rock, former lava flows. The important of this difference will become apparent farther along in our discussion on the subject of basin-floor subsidence during deposition of the Newark strata.

In the swampy lowland enclosed between the Watchung ridges and the marginal highlands, ground elevations lie in the range of 150 to 250 feet. A terminal-moraine ridge crosses this intermontane lowland from Morristown to Summit, New Jersey.

Not including the Delaware River, five important rivers head in the highlands lying NW of the outcrop belt of the Newark strata and flow into- or across the Newark lowland. From NE to SW, these are the Ramapo, Pequannock, Rockaway, Whippany, and Raritan. The drainage areas of three other rivers, the Hackensack, Saddle, and Passaic, are confined chiefly to the Newark lowland.

The Ramapo River heads in Central Valley (near the toll plaza, close to the junction of the NYS Thruway and Rte. 17), and flows S and SE through the highlands underlain by Proterozoic rocks. The Ramapo enters Newark lowland at Suffern. Here, it turns SW and flows along the boundary between the lowland and the Ramapo Range to its junction with the Pequannock at Pompton Plains [UTM 560.4E - 4535.8N, Pompton Plains 7.5-min. quadrangle]. Within the Newark lowland, the Pequannock locally forms the boundary between Passaic and Morris counties. The combined flow of the Ramapo and Pequannock forms the short Pompton River, which ends at Two Bridges in the Town of Caldwell, Essex County, where it joins the Passaic River [UTM 561.2E - 4522.3N, Pompton Plains 7.5-min. quadrangle].

The Passaic River originates in the Great Swamp near Bernardsville and New Vernon, an area underlain by Newark strata, and flows generally northeastward; much of its course lies within the low area enclosed by the curving Watchung ridges. The combined Passaic-Pompton rivers flow out of this lowland through prominent topographic gaps: through Preakness Mountain (Second Watchung) at Little Falls [UTM 564.5E - 4525.6N, Paterson 7.5-min. quadrangle] and through the First Watchung Mountain (Orange Mountain) at Passaic Falls (Great Falls), Paterson [Stop 4; UTM 568.9 E - 4529.5N, Paterson 7.5-min. quadrangle (See Figure 6.)]. (We discuss these two water gaps further in a following section entitled Drainage History.) At Passaic, the Saddle River joins the Passaic River. Newark Bay has formed where the confluence of the Passaic River and the Hackensack River has been submerged.

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 sheet. The Newark Supergroup rests nonconformably above 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 NW of the Ramapo fault zone. Here, they underlie the Ramapo Mountains, a tract of hilly, highly glaciated crystalline rocks whose structurally complex lithologic units trend northeast-southwest, parallel to the strike 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. 14, and 30 (Merguerian and Sanders, 1990; 1994c). And, as we have seen on trips to Staten Island (Merguerian and Sanders, 1989; 1991c; and 1994e), 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 truncated 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 Hofstra University, a few thoughts about the rocks beneath our van tires. The crystalline bedrock of New York City marks the southern terminus of an important sequence of metamorphosed Proterozoic- to Lower Paleozoic rocks of the Manhattan Prong (Figure 7) that widens northward into the New England Upland physiographic province.

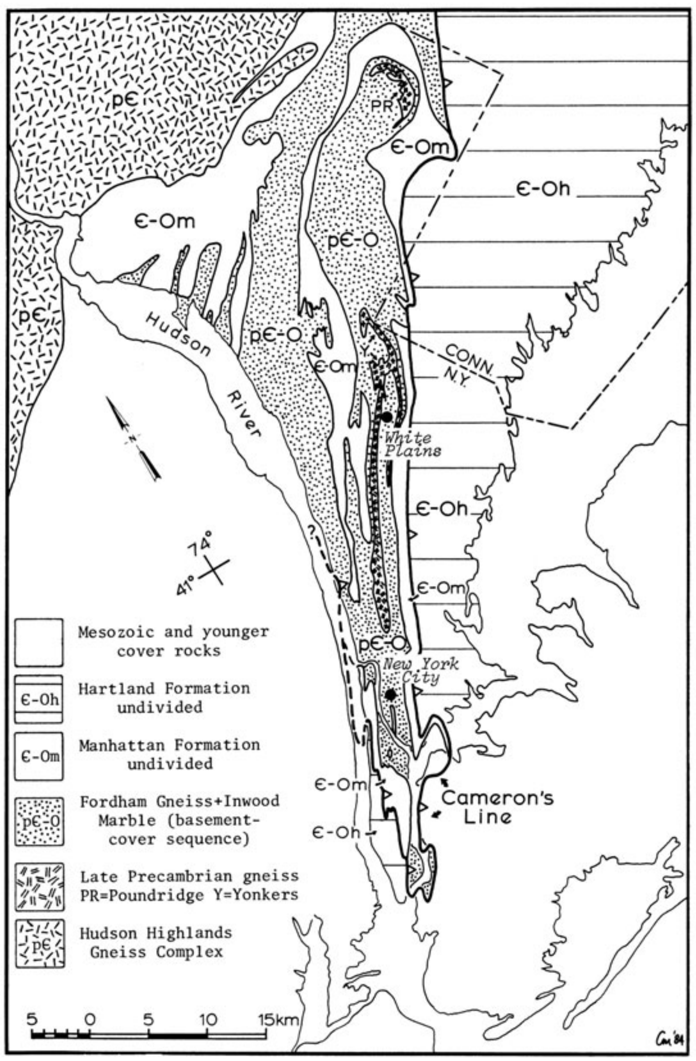


Figure 7. Simplified geologic map of Manhattan Prong showing the distribution of metamorphic rocks ranging in ages from Proterozoic to Early Paleozoic. Most intrusive rocks have been omitted. (D. G. Mose and Charles Merguerian, 1985, fig. 1, p. 21.)

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 Ga (billion years ago). This complexly deformed basement sequence of Layer I constitutes a remnant of the ancient continental crust of proto-North America.

The Paleozoic bedrock units in New York City (Layer II) now form a deeply eroded sequence of highly metamorphosed, folded and faulted sedimentary- and igneous rocks (Figure 8). After the older basement complex had been elevated, exposed, eroded, and subsided the Paleozoic units were deposited above them. This pre-Paleozoic erosion surface marks a gap in the geologic record known as a surface of unconformity. CM has encountered it in studying numerous borings from New York City construction projects housed at Hofstra University and Leo Hall (1968a,) has mapped it in White Plains, New York, and vicinity (Figure 9).

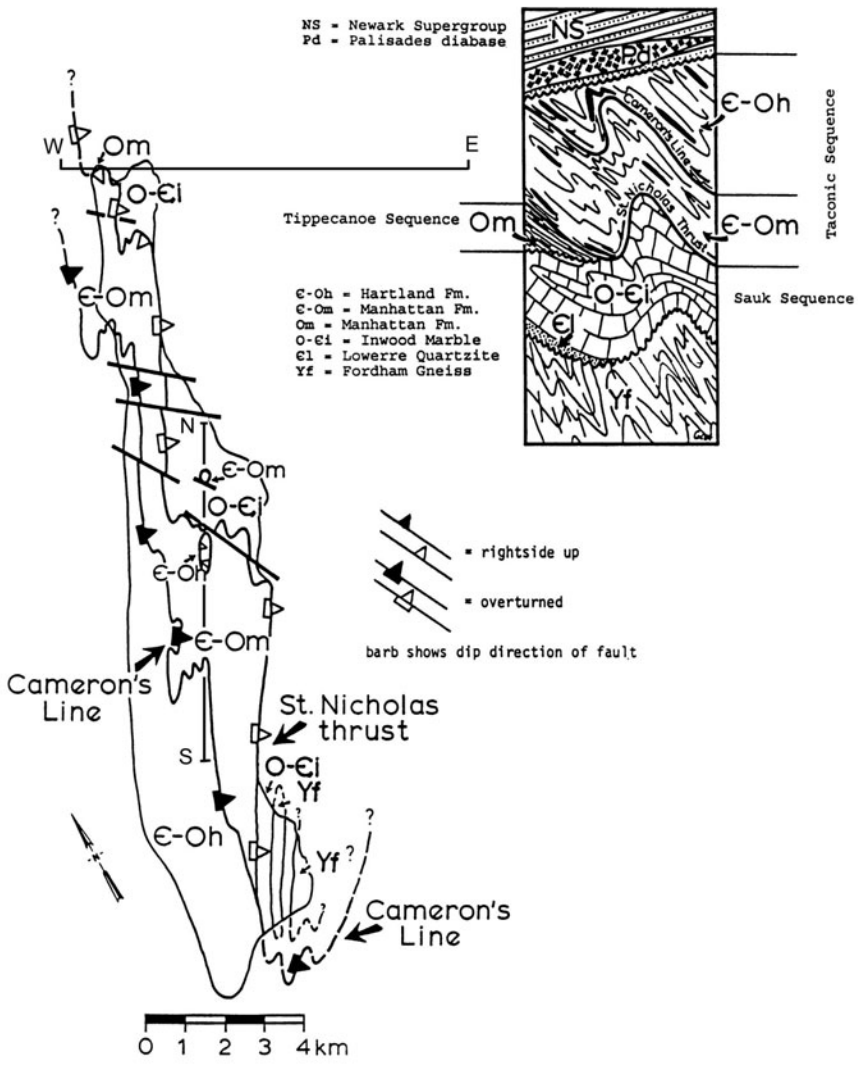
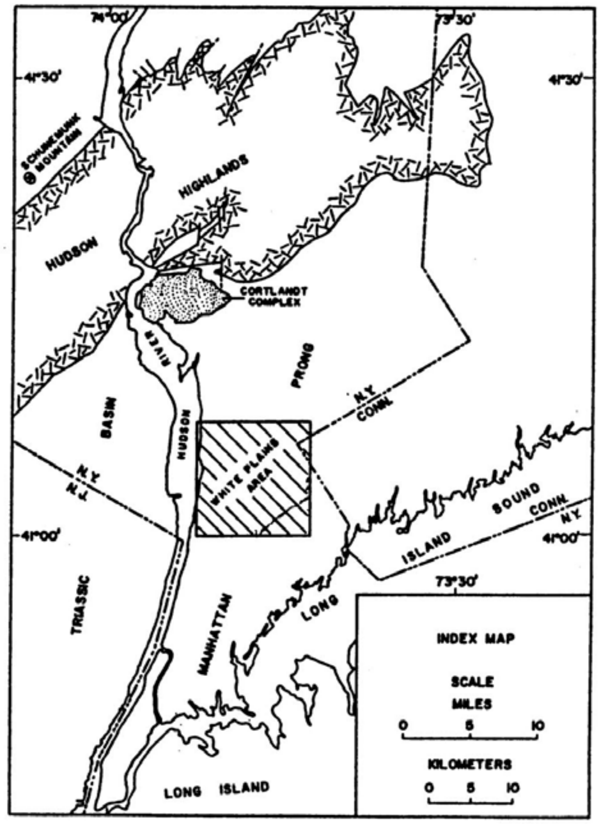


Figure 8. Bedrock geologic map and tectonostratigraphic section of Manhattan Island. (Charles Merguerian, unpublished data.)



Index map for the White Plains area.

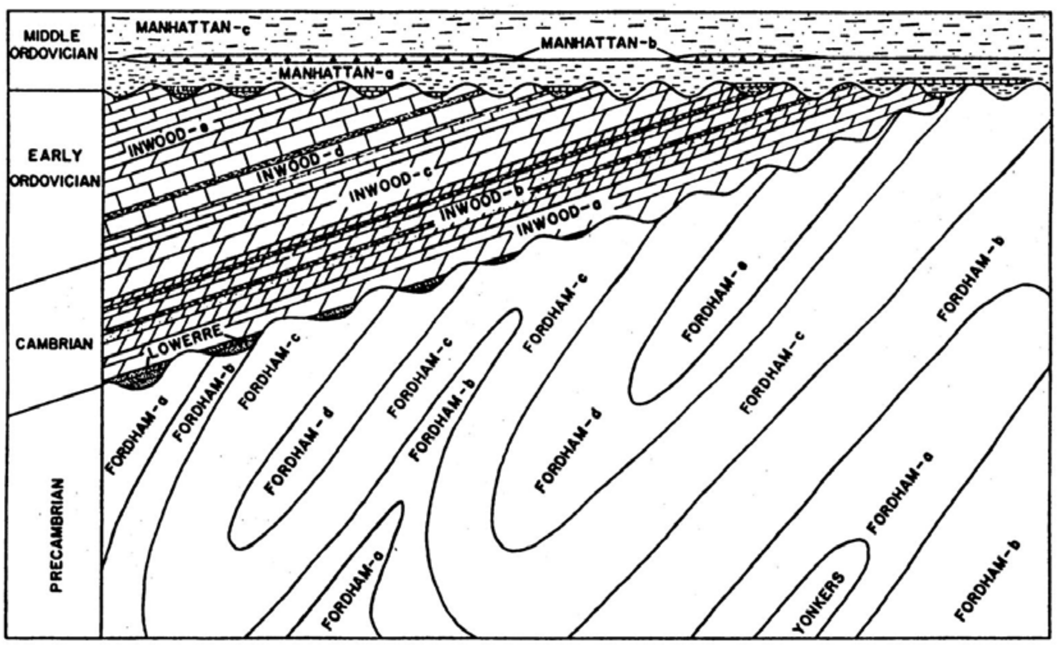


Figure 9. Restored stratigraphic diagram of Manhattan Prong showing relationships when Layer IIB was being deposited across tilted edges of Layer IIA(W), which in turn had been deposited across folded and eroded beveled edges of Layer I. (Leo Hall, 1968a, b.)

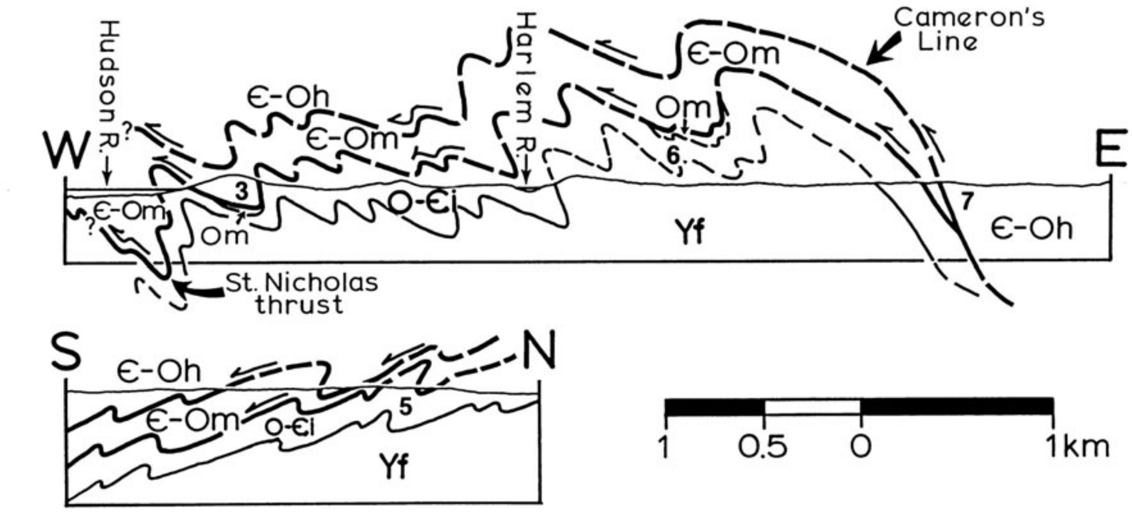


Figure 10. Geologic section showing folded Taconian overthrusts (the St. Nicholas thrust and Cameron's Line) mapped on Manhattan Island and the Bronx. W-E section extends into the Bronx. Lines of sections and symbols defined on Figure 6. (Charles Merguerian, unpublished data.)

The formations of Layer II were deposited as thick bodies 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 the Cambrian Lowerre Quartzite and Cambro-Ordovician Inwood Marble (originally sandy and limey sediments, respectively; it is the eastern part of the Sauk Sequence of Sloss, 1963). Farther east, in the former offshore direction (which in the Early Paleozoic was to the south, not to the east, the offshore direction today), fine-textured terrigenous time-stratigraphic equivalents of the shallow-water strata of the shelf sequence were evidently deposited in deep water [Layer IIA(E)], presumably on oceanic crust. This inferred deep-water sequence is also of Cambrian to Ordovician age. In upstate New York, it is known as the Taconic Sequence (named from the Taconic Range, where it is prominently exposed) and in Manhattan (Merguerian 1995a), as units Є-Ot and Є-Oh of the Manhattan Schist(s). (See Figure 8.)

Layer IIB consists of younger strata that depositionally overlie, and thus were originally above, the western shallow-water platform/shelf strata [Layer IIA(W)] of the Sauk Sequence. In New York City, it is the Manhattan Schist unit Om, which belongs to the lower part of the Tippecanoe Sequence of Sloss (1963). According to CM, at Inwood Hill Park in Manhattan (Merguerian and Sanders, 1991b), this unit (Om) is demonstrably interlayered with the Inwood Marble and contains thin layers of calcite marble (Balmville equivalent) at its base. This field evidence is used to indicate that unit Om of the Manhattan Schist(s) is in place where found and is therefore not older nor the same age as Manhattan unit Є-Ot or Hartland unit Є-Oh. Accordingly, it should not be classified with these two units.

During a series of Paleozoic mountain-building episodes (the Taconic, Acadian, and Alleghanian orogenies), the sedimentary protoliths [Layers IIA(W and E) and IIB] of the New York City rocks were folded and metamorphosed into the Lowerre Quartzite, the Inwood Marble, and the Manhattan Schist(s). Here, the term schist(s) is intentionally plural to indicate that the unit formerly mapped as a single formation, the Manhattan Schist, is actually composed of three, ductile-fault-bounded units (Units Om, Ꞓ-Ot, and Ꞓ-Oh in Figure 10) that were imbricated during the Taconic orogeny (Merguerian, 1983a, 1995; Merguerian and Baskerville, 1987). CM therefore interprets much of the bedrock in New York City as being allochthonous (a fancy term intended to confuse the layman which simply means transported from somewhere else or not deposited where found today!) and the root zone for much of this sequence is thought to be from the broad tract of land to the east of Cameron's Line in western Connecticut and Massachusetts (Merguerian, 1983b).

As such, Cameron's Line, which CM has now traced through the heart of New York City, marks a fundamental plate-tectonic boundary separating autochthonous rocks (another fancy word to confuse and impress the general public which means "in place" or deposited where found) of North America (the Fordham, Lowerre, Inwood, Manhattan Unit Om) from allochthonous rocks of the "Manhattan Formation" (Ꞓ-Ot and Ꞓ-Oh). A simplified geologic section is shown in Figure 2 that is drawn roughly east-west across the latitude of the George Washington Bridge (GWB). Note that the New York City bedrock units are strongly folded into overturned anticlines and synclines and nonconformably overlain by the Newark Supergroup. The surface of nonconformity projects out of the Hudson River over Manhattan and dips toward the west along with the overlying units of the Newark Supergroup.

Layer V: Newark Strata and the Palisades Intrusive Sheet

Because our discussion of Layer V (the Newark strata and the Palisades intrusive sheet) is so long winded and includes so many topics that we have subdivided it into subsections as follows: General Geologic Relationships, Stratigraphic Relationships, Paleogeographic Relationships, Associated Mafic Igneous Rocks, and Tectonic History.

General Geologic Relationships

The Newark strata of Layer V constitute one of the significant "layers of geology" (Levorsen, 1933, 1934, 1943, 1945, 1948, 1954, 1960, 1964) in the New York City region. As mentioned, Newark strata of Layer V nonconformably overlie the older metamorphic terrane of the Manhattan Prong of Layers I and II. In turn, Layer V is overlain in angular unconformity by the virtually horizontal Upper Cretaceous sediments of the Atlantic Coastal-Plain succession of Layer VI, the basal unit in the wedge of sediments that has been accumulating along the passive eastern margin of the North American continent for the last 170 million years or so. For example, in an outlier at Sand Hill, NJ, Upper Cretaceous strata rest on the exposed edge of the Rocky Hill-Palisades intrusive sheet, a relationship that gives a vague limit for the date of deformation of the Newark rocks (Widmer, 1964). The area of our field trip is shown on the geologic map of the Newark 1° by 2° quadrangle compiled by Lyttle and Epstein (1987).

A well-developed strike valley exists at the base of the Newark strata. (See Figure 2.) The Hudson River follows this strike valley from Haverstraw, NY to Hoboken, NJ. At Hoboken, the Hudson bends to its left, and flows to the south. By doing so, it leaves the strike valley and flows across the metamorphic rocks. (See Figure 3.) In Jersey City, NJ, and on Staten Island, the rocks of the Manhattan Prong are present on the W side of the Hudson River. Farther upstream, the rocks of the Manhattan Prong form the E bank of the Hudson.

Where the Hudson River leaves the basal-Newark strike valley, this strike valley disappears from the modern landscape but does not disappear geologically. The basal-Newark strike valley, filled by Upper Cretaceous- and younger sediments, continues to the SW in the subsurface (Lovegreen, 1974 ms.). This buried subsurface valley extends across western Staten Island. Its continuation, if any, to the SW in New Jersey has not as yet been identified.

Stratigraphic Relationships

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

The age range assigned to the strata composing the Newark Supergroup has oscillated back and forth like a geological pendulum. During the 19th century, based on studies of fossil fish collected from them (Redfield, 1856, 1857), they were assigned to the Jurassic. By contrast, dinosaur remains and -footprints suggested Late Triassic. Given this situation, some geologists classified these strata as Jura-Trias (for instance, Darton, 1902 in the New York City Folio 83 of the U. S. Geological Survey). Many geologists, however, took the Newark strata to be synonymous with Triassic (Cook, 1968, 1879, 1882, 1887, 1888, 1889). By contrast, Kümmel (1897, 1898, 1898a, 1898b) initially used only "Newark." When he became associated with the U. S. Geological Survey Folio projects, however, he used "Triassic" (Kümmel, 1914).

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

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

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

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

Where the three well-known sheets of extrusive basalt (First-, Second-, and Third Watchung basalts; named by Paul Olsen, the Orange Mountain Basalt, Preakness Basalt, and Hook Mountain Basalt, respectively) and/or the distinctive black argillites of the Lockatong Formation are present, the Newark sedimentary strata are easy to subdivide. But where one is faced with an isolated exposure of a non-fossiliferous Newark-type reddish-brown sandstone, -siltstone, or -shale, or even a coarse conglomerate with reddish-brown sandstone matrix, the problem of assigning the correct formation verges on hopeless. Ultimately, some mineralogic- or lithologic criteria may prove to be helpful for stratigraphic assignment.

The basal formation, the Stockton, typically consists of gray- to buff-colored coarse, even pebbly arkose (geologists' name for a variety of sandstone that contains notable quantities of feldspar; depending upon personal preferences, "notable" ranges from 25% to 33% or more). Also present within the Stockton are many layers of reddish-brown sandstone and -siltstone that are not easy to distinguish from the typical strata of the thick Passaic Formation. (See Table of Formations above and Figure 11.) In wells drilled on Staten Island, some difficulty has arisen over how to distinguish the gray Upper Cretaceous sands, which unconformably overlie the Stockton, from the light-colored parts of the Stockton. Experienced geologists rely on the feldspar content. The compositionally mature Upper Cretaceous sands lack feldspar whereas the compositionally immature Stockton contains large quantities of feldspar.

The next formation going upward in the Newark Supergroup is the Lockatong, which typically consists of a dark-gray- to black, tough-to-break rock named argillite. Toward the SW, the thickness of these two formations is much greater than in the Watchung syncline. In the Delaware Valley, for example, the thickness of the Stockton is 1650 m and that of the

Lockatong, 1200 m (McLaughlin, 1959, p. 85). The Lockatong Formation is the unit into which the tabular, generally concordant Palisades sheet has been intruded.

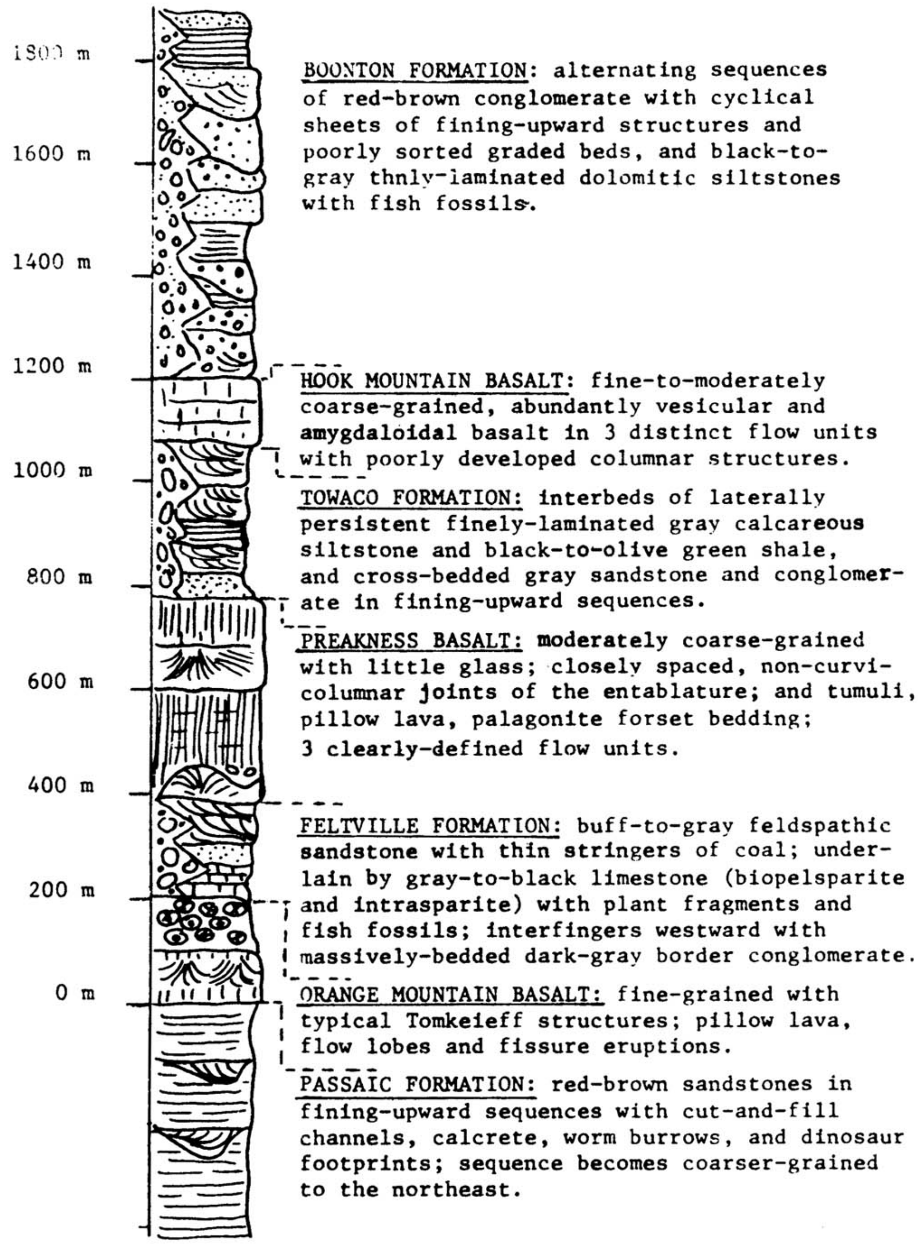


Figure 11. Columnar section of Newark Supergroup from upper part of Passaic Formation to Boonton Formation. (Warren Manspeizer, 1980, fig. 5, p. 319)

Above the Lockatong is the Passaic Formation (lower part of former Brunswick Formation, now the Brunswick Group), whose thickness in the Watchung syncline Olsen estimates at about 6000 m, is more covered than exposed. The predominant aspect of the Passaic Formation is its characteristic red-brown color. This color has left its imprint on most of the Pleistocene sediments.

Paleogeographic Relationships

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

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

Hydrologic Situation in Nonmarine Basins. In addition to its importance as a medium for sedimentation, water controls organisms. If water is present, plants grow. If not, no plants can survive. And, without plants, no animals can exist. Dinosaur footprints found in some Newark strata imply that dinosaurs were numerous, which in turn, must have meant that vegetation, hence water, was plentiful. How can evidence for abundant water implied by the large number of dinosaurs to make footprints and for lack of water implied by the footprints themselves be reconciled? Several such ways are possible. These include: permanent through-flowing rivers that head in areas where rainfall is abundant; ground water flowing basinward in shallow aquifers consisting of tongues of coarse sediments that extend from the marginal highland out into the basin-floor lowland; contrasting wet- and dry seasons; and climatic changes involving a shift from dry to wet and back to dry again.

The Nile River, Egypt, is an example of a permanent, through-flowing river that arises in a wet-climate zone and flows across a desert with enough discharge so that it does not dry out. As pictures taken from satellites amply demonstrate, the banks of the Nile are lined with trees. Only a short distance away from the river is a treeless desert. As pointed out by the pioneer American meteorologist, William Ferrel (1863), the annual flood of the Nile is controlled by the northward migration of the zone of vertically rising air that is associated with the sub-solar point (place on Earth where the Sun's rays arrive at normal incidence). This zone of updrafts is also a zone of torrential rainfall; it is known as the Intertropical Convergence Zone (abbreviated ITCZ). According to Ferrel, during Northern-Hemisphere summer, when the ITCZ migrates northward away from the Equator, following the Sun, its torrential downpours soak the Ethiopian Highlands, the headwaters of the Blue Nile (Figure 12). The flood subsides when the ITCZ migrates southward taking its rainfall with it.

Similarly, the ITCZ migrates southward into the Southern Hemisphere during Northern-Hemisphere winter (southern Summer). Accordingly, at the extremes of this annual migration only a single rainy season takes place. Localities in between experience two rainy seasons, one when the ITCZ passes over from N to S, and the other, when it comes back headed from S to N.

Another way is for water to be abundantly supplied to a desert is to move underground within tongues of coarse, permeable sediment that extend into the basin-floor desert from the basin-marginal highlands. Abundant rainfall in the highlands that recharges these shallow aquifers can be transported in the subsurface into a desert area. An example is the tropical "rain" forest at Lake Manyara National Park, Tanzania (35°50'E, 03°20'S; Figure 13). This forest is a distinct anomaly; it grows within an area where rainfall is a rarity; the surrounding territory is a bone-dry desert. But in the midst of this desert is a tract that is so lushly vegetated that it supports an abundant fauna including herds of large vertebrates. The plants are able to grow here because their roots derive water from shallow aquifers in the basin-marginal fan sediments. The aquifers are recharged in the highland at the margin of the basin. Thus, the Lake Manyara tropical "rain forest" is really a tropical "ground-water" forest.

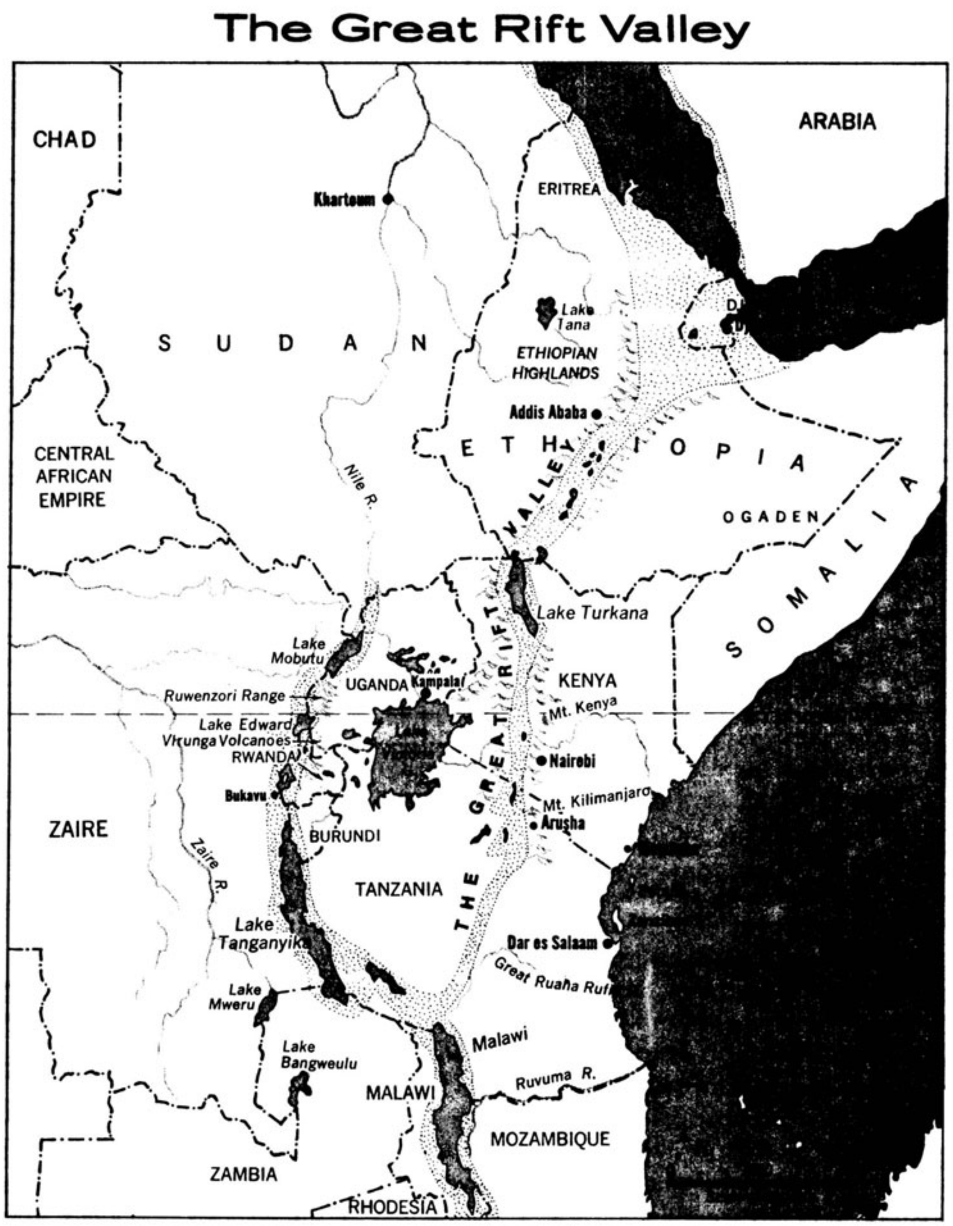


Figure 12. Map of northeastern Africa showing The Great Rift Valley extending from Tanzania to the Red Sea and the Ethiopian Highlands, headwaters of the Blue Nile. (Tanzania Geological Survey map.)

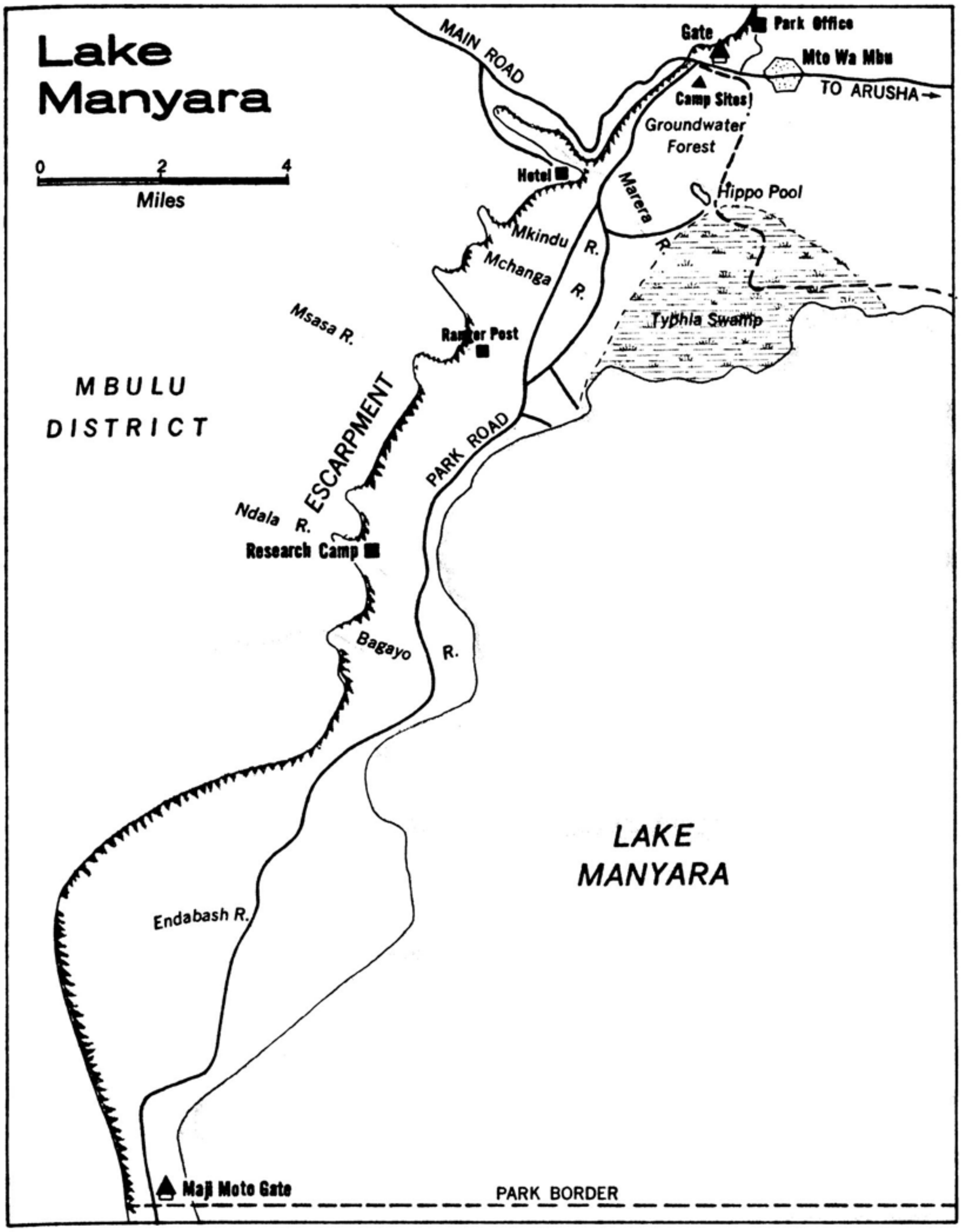


Figure 13. Map of northeastern part of Lake Manyara Park, Tanzania, showing Typhia Swamp and Groundwater Forest. (Tanzania Park Service map.)

Another way in which water can appear in an otherwise-dry setting is for wet- and dry seasons to alternate. Rainfall could come more or less regularly during one- or two short seasons. The monsoon belt of India is an example of a region receiving one-season rainfall. As with the Nile floods, the monsoon season in India accompanies the annual northward migration toward the Tropic of Cancer of the ITCZ (Friedman, Sanders, and Kopaska- Merkel, 1992, p. 282-286).

Still-another way is for the climate to change. During the Pleistocene Epoch, the tropical regions experienced dramatic shifts from wet times, known as pluvials, and dry times (interpluvials). The arid times in the tropics coincide with glacial-age climates elsewhere. The accompanying high winds propelled much dust high into the stratosphere, where the high-altitude winds sent it around the world. Interglacial times in the tropics were marked by abundant rainfall and lush vegetation; under these conditions, the amount of atmospheric dust was greatly diminished. [These times of contrasting abundance of atmospheric dust have been logged in the latest ice cores drilled in Greenland. Zones of dusty ice can be recognized by their higher electrical conductivity (related to the feldspar content in the dust). Continuous resistivity logging enables a graph to be constructed that shows dust content vs. depth (and down to a certain level, at least, depth is a direct function of age). The Greenland ice dated as having been deposited during the last glacial episode shows many sharply defined zones of dusty ice (implying glacial climate) alternating with zones low in dust, which imply nonglacial climate (Taylor and 9 others, 1993). An astonishing attribute of this electrical-resistivity logging of the ice cores is the abruptness of the change from dusty zones to low-dust zones. These imply that the climate shift from one mode to the other was very rapid (within a few tens of years).]

As we shall see, the strata that filled the Newark basin were deposited under contrasting hydrologic settings. Some of them were deposited in a deep lake that may have filled much of the basin, just as Pleistocene Lake Bonneville filled the Great Salt Lake lowland in north-central Utah 20,000 yrs ago. Typical deep-lake deposits are microlaminated black shales containing abundant remains of fossil fish. Other strata accumulated subaerially in a dry climate. Typical features of such strata are desiccation cracks, dinosaur footprints, and paleosol caliche. Paul Olsen (1986) has given the name Van Houten cycles to lake deposits made during a change from deep water to shallow water (or even no water) and back to deep water again. Such changes characterize lakes in closed drainage basins. The water-level fluctuations are controlled by climatic changes.

Studies of the cyclicity by Van Houten (1962, 1964) and Olsen (1984, 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-modeling gurus who claimed that the Milankovitch periodicities break down within a few million years have been using the wrong numbers in their formulae.

Some Relationships Between Water and Sediment

As extremes, let us contrast the conditions and deposits of a debris flow generated during a flash flood with those that prevail in a meandering stream that continues to flow between rain storms (thus proving that it is fed by springs and/or general seepage from the ground water).

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

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

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

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

If you find any cross strata, it is possible to determine the directon of flow of the ancient currents. The key to interpreting cross strata is that they dip in the downcurrent direction. The main point to be established before the interpretation can be considered complete is to determine the three-dimensional attitudes of the cross strata. If they are planar, then the interpretation is not complicated (Figure 14). If they are cuspate (spoon shaped), the one needs to find the median line of the cusp. Cuspate cross strata dip through directions that may span an azimuth of 270°. Cuspate cross strata are concave downcurrent (Figure 15).

Associated Mafic Igneous Rocks

Associated with the Newark sedimentary strata are sheets of mafic igneous rocks including both intrusives (the Palisades sheet) and extrusives (the three "Watchung" basalt sheets in the Watchung syncline and several scattered areas along the Ramapo fault and elsewhere). The significance of these contrasting kinds of sheets will become apparent from the following discussion, which begins with the Palisades sheet.

The Palisades Intrusive Sheet. The world-renowned mafic Palisades intrusive sheet is continuously exposed along the east edge of the Newark Basin from west of Haverstraw, New York southwestward to Staten Island, New York City where it passes beneath an intertidal salt marsh. (See Figure 1, cover.) The sheet continues southward, although with limited exposure, into New Jersey and Pennsylvania within the Delaware Subbasin. We discuss this sheet by first debating the use of the term sill for it. Then we take up its mode of intrusion and our new data on its paleoflow direction with possible feeder on Staten Island. Then follows contact relationshps, chilled-margin facies, discordant contacts, and clastic dikes. These raise the issue of the state of lithification of the sediments at time of intrusion and provide another way of estimating the depth of intrusion.

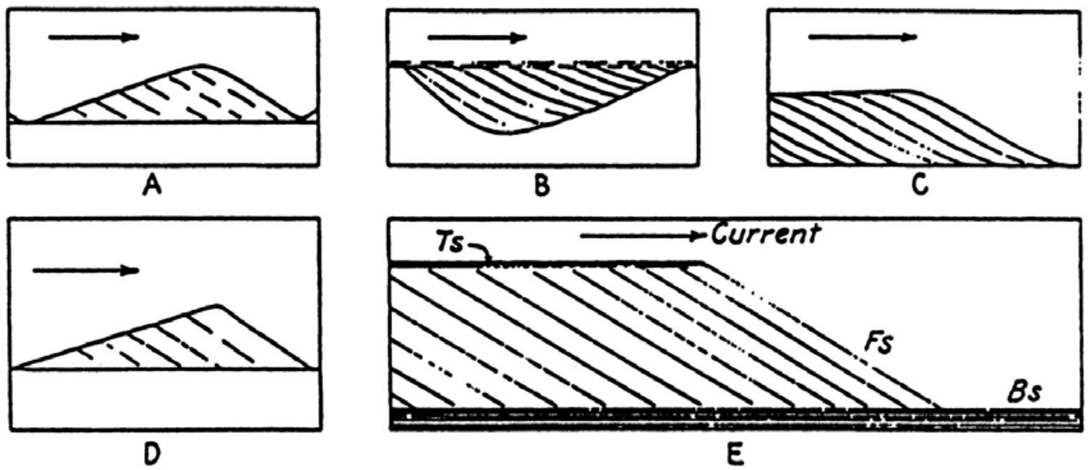


Figure 14. Sketches of cross strata dipping to the right and formed by current flowing from left to right.
A and D, Longitudinal profiles through individual bed forms that have migrated to the right (downcurrent) by at least one
wavelength, thus preserving as internal cross strata many former downcurrent faces.
B, Longitudinal profiles through cross strata that have filled in an asymmetric depression.
C and E, Longitudinal profiles through cross strata deposited by downcurrent growth of an embankment (such as a delta lobe), built where the flow enters slightly deeper water. (R. R. Shrock, 1948, fig. 207, p. 245.)

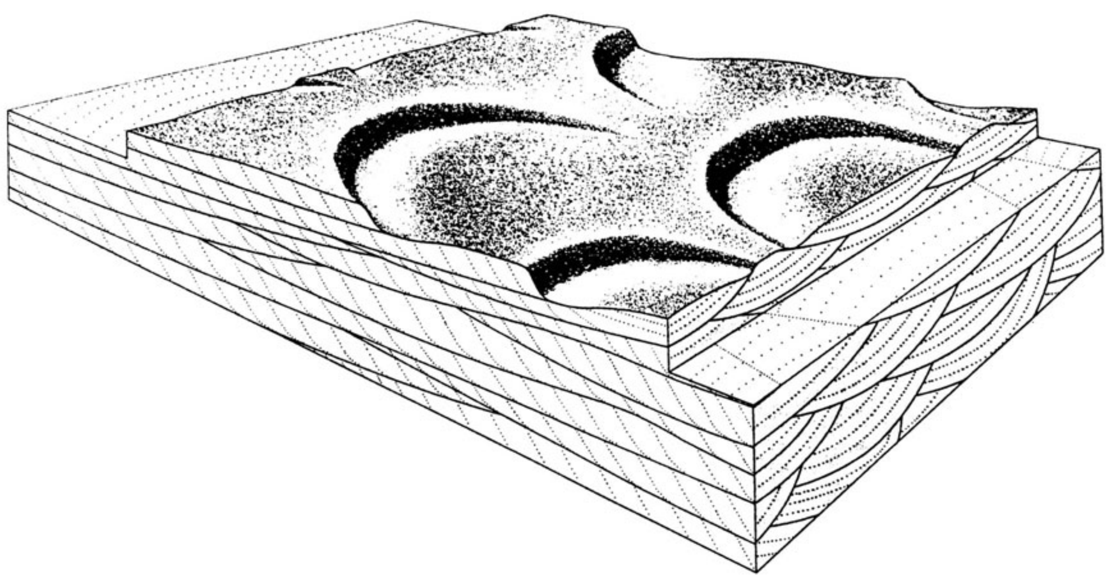


Figure 15. Block diagram showing cuspate (lunate megaripples) and how their downcurrent migration forms trough-type cross strata. Current from upper left to lower right. (H.-E. Reineck and I. B. Singh, 1980, fig. 52, p. 43.)

"To be or not to be (a sill)" - only your local geologists know for sure. Prior use of the word "sill" to describe the Palisades intrusive sheet implies that the contacts of this sheet are everywhere concordant with the bedding of the country rock. In many places such concordance prevails. But on an individual- outcrop basis and near its ends, discordance has been demonstrated. The author of a recent article on the Palisades Sill berates his readers with "four common misconceptions" the first of which is:

"that the Palisades Sill extends only from Staten Island to near Suffern, New York (Fig. 1), and that the intrusion (sic) is largely sill-like as viewed along strike. Although the Palisades generally is conformable (sic) within the Newark Supergroup in northern New Jersey, it clearly is discordant at its northern end (Fig. 1). In addition, drill-hole (sic) and geophysical data show that the Palisades reemerges from beneath Cretaceous sedimentary cover as the Rocky Hill diabase in the central Newark basin (Fig. 1; Lewis, 1907). Post-intrusion normal faulting again reexposes the Palisades Sill farther west as the Lambertville Sill (Husch, Sturgis, and Bambrick, 1984). Both of these diabase bodies are discordant, particularly at their southwestern ends. Thus, the expanded Palisades body, exposed over a strike length of about 150 km (Fig. 1), is not a sill at many localities and would better be described as a sheet" (Husch, 1990, p. 699). What Husch wrote about the sheet in central New Jersey is accurate, but we think that in the other direction, Husch has joined the flock who have lost sight of the importance of strike and dip.

[Explanation of (sic's): No. 1, after "intrusion" is there because the correct word should be intrusive; intrusion is a process; an intrusive is a body of rock that results from the process intrusion. How many geologists do you know who don't know their processes from their products in the ground? No. 2, after "conformable" is there because the correct word should be concordant. The (sic) means that we have copied faithfully what the author wrote, but are signalling our contention that wrong usage exists.]

We think that all the along strike diagrams that have been drawn in which show the Palisades sheet climbing from low in the Newark toward the top of the Newark, starting at Nyack, New York, do nothing more than display the prevailing ignorance of the effects on the Newark strata (including the Palisades sheet) of the transverse Danbury anticline (Sanders, 1960; Merguerian and Sanders, 1994a). JES (both privately and at cocktail parties) has always contended that the curvature of the Palisades sheet from Nyack to a point west of Haverstraw (near the Palisades Interstate Parkway) is not (repeat NOT) the result of a change from a concordant- to a discordant sheet and thus that it climbs in the stratigraphic succession from near the bottom to up near the top, but rather merely reflects the effects of the transverse Danbury anticline. The Newark strata have been folded, folks. And by not one but by two anticlines whose axes are disposed at right angles. Thus, the attitudes of the sedimentary strata swing around from a NNE strike and WNW dip (a result of being on the NW limb of the regional anticline whose axis trends NNE-SSW) to a NW strike and a SW dip (a result of being on the SW limb of the regional Danbury anticline whose axis trends NW-SE). Only locally near its NW termination does the sheet become discordant; the amount of this discordance is not more than a few hundred meters. How this profoundly important point of regional structural geology can continue to elude otherwise-rational individuals is a complete mystery to us. Look on a regional map. Does the curvature of the outcrop belt of Palisades sheet differ significantly from those of the Watchung extrusives?

Because this sheet of mafic igneous rocks is not concordant along its strike length (Figure 16), we have abandoned the formerly used term Palisades "sill." Rather, from Staten Island northward to Haverstraw, the sheet climbs discordantly upward through the strata from the Lockatong formation (New York City area) to the Passaic Formation (Haverstraw area). Extensions of the Palisades to the SW, (the Lambertville Sill and Rocky Hill intrusive of the Delaware Subbasin) mirror the climbing stratigraphic discordance displayed in the Newark Basin. (See Figure 16.) As such, the longitudinal profile of the Palisades indicates a lopolithic intrusive [following the definition of Grout (1918)]. However, at the NE end, post-intrusive deformation along the transverse Danbury anticline has created much of the hook-like map pattern (Merguerian and Sanders, 1994c, d; See Figure 5.)

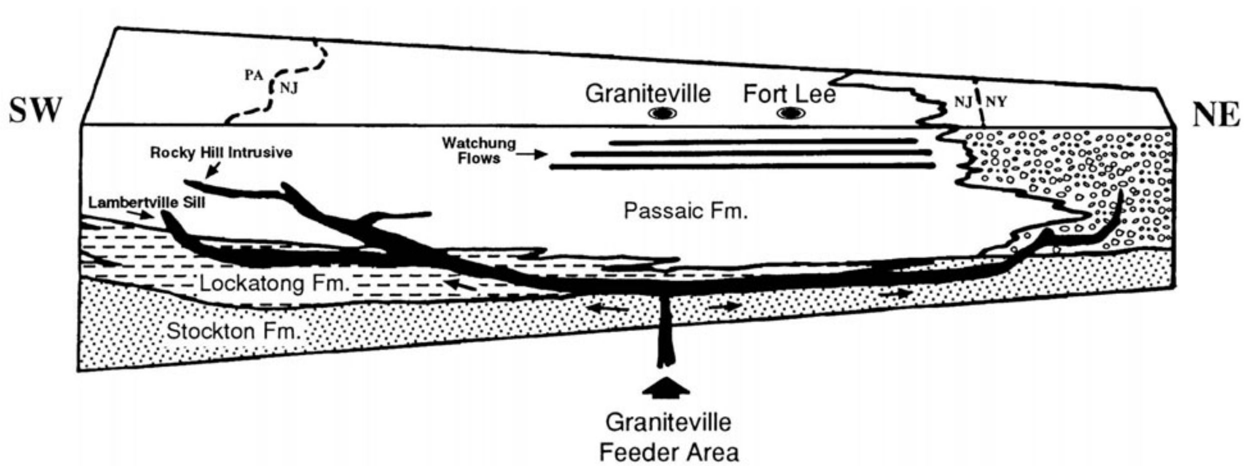


Figure 16. Block diagram showing SW- to NE-trending longitudinal profile (not to scale) of the Palisades intrusive sheet of the Newark Basin and its extension southward into the Delaware Subbasin showing, with arrows, our interpreted paleoflow patterns. Note the overall lopolithic form to the intrusive sheet as viewed in this orientation and the low stratigraphic position of the central part of the sheet including our conjectured feeder area at Graniteville, Staten Island. The positions of Fort Lee, NJ and Graniteville, NY are shown on the top (map view) of the block diagram. (After F. B. Van Houten, 1969, fig. 1, p. 315).

Mode of Intrusion. Historically, the Palisades has been viewed as a concordant sill-like body, the product of a single charge of magma that differentiated in situ by gravity settling [Darton (1889, 1890), Kummel (1899a, b), Lewis (1908a, b), Walker (1940), Hess (1956), Lowe (1959), and Thompson (1959)]. More recently, however, evidence has mounted that the Palisades sheet is composite. It is inferred to have formed as a result of several injections of already differentiated magma [Walker (1969), Puffer, Geiger, and Camanno (1982), Shirley (1987), Puffer (1987, 1988), Husch (1990), Puffer, Husch, and Benimoff (1992)]. Today, the major unanswered questions center on the consanguinity of the intrusive pulses of the Palisades magma charges and their possible synchroneity with extrusion of one or more of the "Watchung" (Orange Mountain, Preakness, and Hook Mountain) basalt flows.

Our efforts have sidestepped this continuing inquiry into the possibilities of comagmatic ancestry. In search of a better understanding of the environmental conditions that prevailed during injection of the Palisades magma(s), we have focused on the basal contact relationships (Merguerian and Sanders, 1992, 1995b, 1995c). Thus far, these studies have placed constraints on the paleoflow direction of the magma and on the state of lithification of the bounding sediments, and have enabled us to estimate that the depth of intrusion of the Palisades magma(s) lay in the range of ~3 to 4 km.

Contact Relationships. The lower contact of the Palisades intrusive sheet with presumably in-situ sedimentary rocks of the Lockatong Formation is spectacularly exposed on the Palisades Interstate Park access road beneath the George Washington Bridge. The rocks at this locality have been studied by many geologists, including Van Houten (1969), Olsen (1980b), and Puffer (1987). The fact that the olivine zone lurks above the roadbed allows us to infer that most of the Lockatong here has not been detached although some Lockatong screens and xenoliths are present. Within the larger xenoliths, it is possible to see the cyclic successions of strata (Van Houten cycles) that are inferred to have been deposited as the ancient lake level fluctuated (Olsen, 1980a).

These sedimentary strata have been contact metamorphosed; the contact with the Palisades intrusive locally is discordant. Present also are folds as well as numerous nondeformed clastic "dikes", which crosscut the primary igneous-sedimentary contact. Contact-zone breccias include those with angular pieces of basalt in a "matrix" of light-colored feldspathic sand.

The columnar-jointed basal part of the Palisades intrusive in New Jersey is interrupted at the level where olivine has been concentrated. The olivine zone lies above a chilled zone of aphanitic- to glassy basalt (Figure 17). The sizes of the crystals in the igneous rock here change profoundly with distance above the contact. At the contact, the texture is aphanitic to glassy. With increasing distance from the contact, the texture becomes gradually coarser. As a result, many gradations and discrete mixtures can be found, from microvesiculated- to hypocrystalline basalt to aphanitic basalt (near the contact), to dolerite (a few meters above the contact), to gabbro (a few tens of meters above the contact). Local microvesicles in glassy basalt and a pipe amygdale in the base of the Palisades sheet, together imply that the mafic magma was chilled extremely rapidly and that Newarkian pore water, formerly present in the sediment, was transformed into a vapor phase, thus enabling the sediments to become fluidized.

The contact zone displays excellent products of contact metamorphism and disrupted Lockatong bedding. As noted previously by Van Houten (1969), the layers of original argillite have been converted into a black hornfels consisting of biotite and albite with minor analcime, diopside, and calcite, or to green hornfels consisting of diopside, grossularite, chlorite, and calcite, with subordinate biotite, feldspar, amphibole, and prehnite. Miller and Puffer (1972) and Puffer (1987) have noted pinite after cordierite and tourmaline as porphyroblasts in the hornfels. Our studies indicate that although contact metamorphism has changed them to a lesser degree than the argillites, near the contact, the sandy Lockatong interlayers, are chaotic. As described below, they have been "intruded" upward into the chilled zone where they form irregular "sedimentary apophyses" more than 20 cm long.

Palisades Chilled-margin Facies; Aphanitic Basaltic Sills and Dikes. Two kinds of products that formed by rapid chilling in the contact zone are present; (1) the chilled border of the main sheet, and (2) aphanitic basalt as small dikes and sills that cut various units in the contact zone.

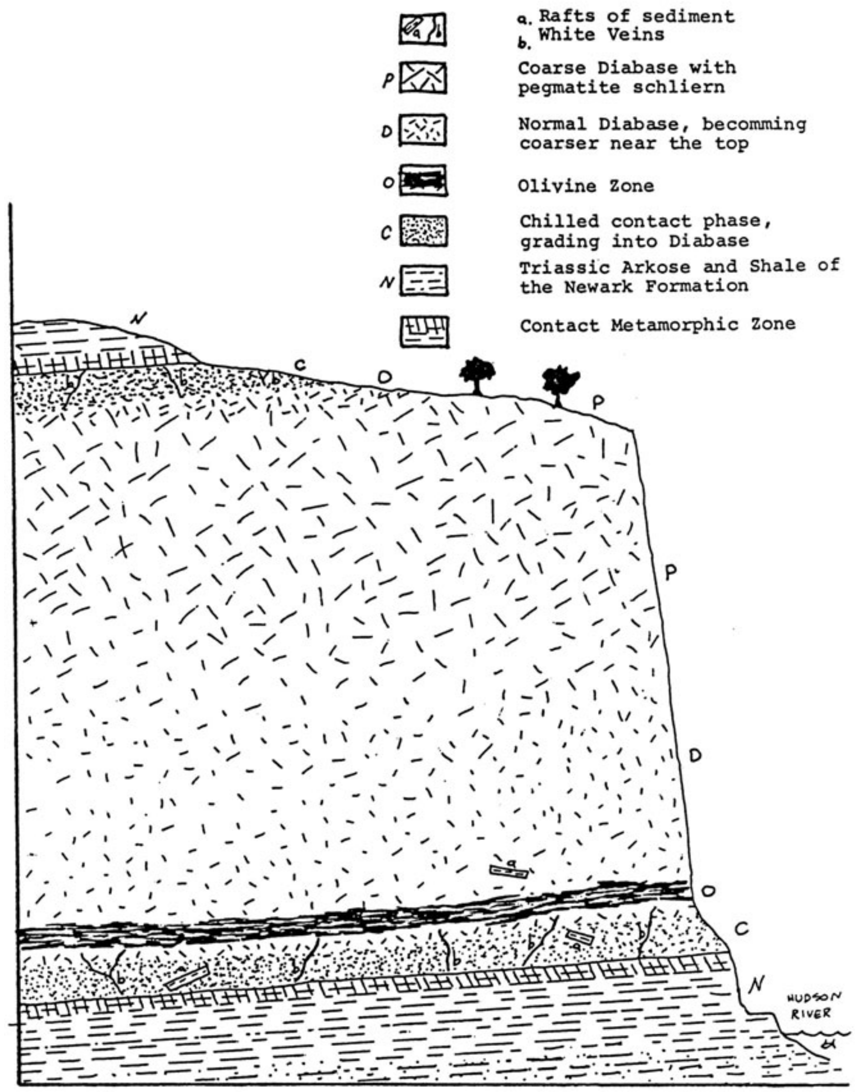


Figure 17. Schematic profile-section through Palisades intrusive sheet, New Jersey. (M. J. Sichko.)

As mentioned, close above the basal chilled-margin contact of the Palisades intrusive in Fort Lee, olivine has been concentrated. The basal igneous rocks display gradations and mixtures among micro-vesiculated to hypocrystalline basalt to aphanitic basalt (near the contact) to dolerite (a few meters above the contact). The microvesicles and a 15-cm-long pipe amygdale extending upward from the Lockatong into glassy basalt imply that the mafic magma was chilled extremely rapidly and that Newarkian pore water, formerly present in the sediment, was transformed into a vapor phase, thus enabling the sediments to become fluidized.

Locally, the main sheet has been invaded from below by clastic dikes (discussed in a following section). In some places, clastic dikes have intruded across a minor offset (~1 cm) of a basalt-Lockatong contact but in this instance, the basalt is a 0.5-m sill found intruding the Lockatong. Although a rare feature, commingled within the zone of clastic dikes, a 40-cm-thick basaltic offshoot has been found to intrude a xenolith of partly fused Lockatong. We are not sure whether this offshoot, which can be traced back into the chilled zone, is a primary Palisades chilled-margin phase or the result of a younger Palisades intrusive phase. Thus, in the contact zone, late-stage basaltic dikes have crosscut some clastic dikes; therefore some igneous activity postdates the clastic dikes which themselves were mobilized by magmatic heat.

Discordant Contacts and Deformation. When one focuses on the contact patterns of the igneous- and sedimentary rocks (Figure 18), one cannot help being struck by the discordance exhibited by the top-to-the-north ramp-like contact. In almost every case [including exposures near Bergen [Central Park quadrangle; UTM Coordinates: 584.78E - 4516.75N] and at King's Bluff [Weehauken quadrangle; UTM Coordinates: 582.65E -4513.00N)], the basal contact of the Palisades ramps upsection toward the NE (Figure 19). (See also Figure 5.) The Palisades contact typically migrates gently upsection toward the N; it truncates the bedding in the bounding sedimentary rocks at low angles for distances of a few meters to tens of meters. At the northern end of a ramp, the igneous contact drops abruptly. It truncates the bedding at a high angle, thus creating a broad, saw-tooth contact pattern. Locally, at the leading edges of the Palisades northward-directed ramps, the Lockatong shows broad E-W-trending arches (Figure 20).

Figure 18. Outcrop view of the megascopic saw-tooth pattern produced by north-directed low-angle ramping of the basal contact of the Palisades intrusive sheet along its contact with sedimentary rocks of the Lockatong Formation in Fort Lee, New Jersey. Hammer handle is 40 cm in length and rests immediately below chilled Palisades basalt. (CM photograph).

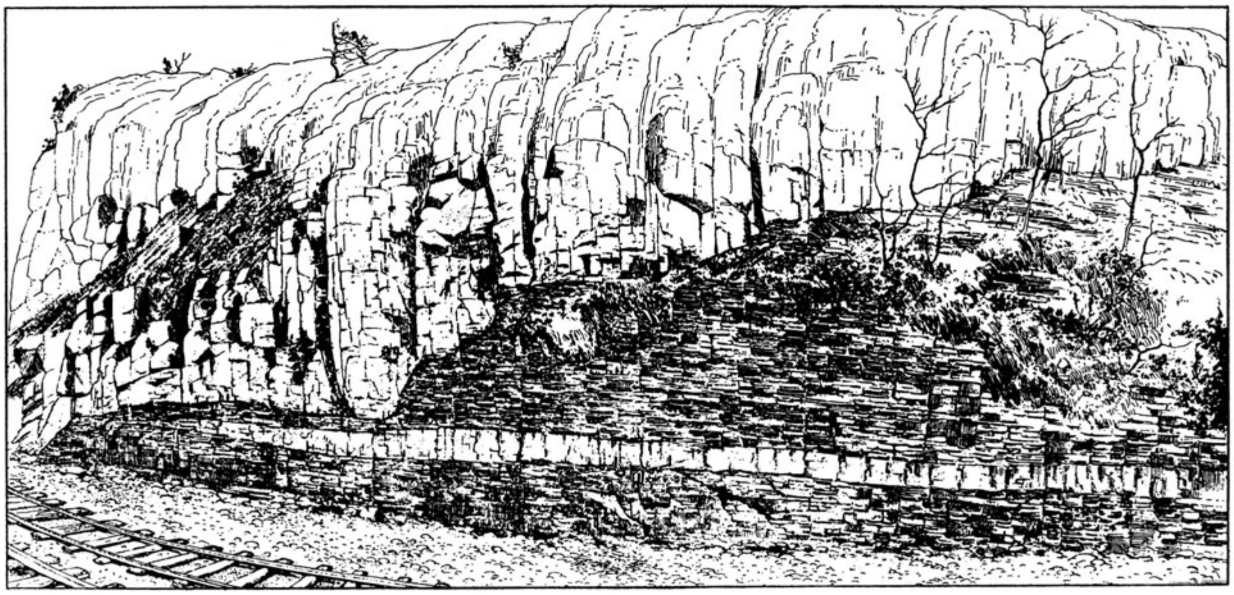


Figure 19. Sketch of Palisades diabase showing lateral ascent of the contact across the strata of the Newark Supergroup. (N. H. Darton, in F. J. H. Merrill and others, 1902, fig. 7, p. 8.)

Figure 20. View of a broad E-W-trending arch of the underlying Lockatong in discordant contact with the leading edge of a north-directed ramp. Hammer handle is 40 cm in length and rests immediately above chilled Palisades basalt contact with the Lockatong. (CM photograph).

The megascopic discordance of the ramp-like contact is obvious, as are localized folds in the bounding sedimentary strata. In one case, about 200 m north of the GWB, a chevron fold with a wavelength of 30 cm, lies immediately below a northward-ramped contact between the base of the Palisades and the Lockatong (Figure 21). The chevron fold plunges ~10° into N75°W with an axial surface oriented N75°W, 90°. After the regional-dip component of the Newark Supergroup has been removed, this structure reorients into a horizontally plunging fold. Argillites below the intrusive contact exhibit asymmetric intrafolial z-folds plunging gently toward the west and with axial surfaces parallel to the intrusive contact, thus indicating top-to-the-right, NE-vergent shear. Elsewhere, folded NE-vergent xenoliths exhibit subhorizontal plunges and steep SW-dipping axial surfaces. The pronounced northward-ramping effect of the basal Palisades contact and the structural evidence together suggest that within the contact zone, top-to-the-northeast shearing prevailed. We can best explain the orientations- and vergences of folds and the discordant northward ramping of the basal Palisades contact by a ductile boundary response to subhorizontal intrusion of a cooling, perhaps gelatinous, high-density mafic magma whose paleoflow pattern was from the SW toward the NE.

Figure 21. View of an upright chevron fold gently plunging into N75°W in contact-metamorphosed strata of the Lockatong Formation. The black arrow, which was drawn immediately above the Palisades-Lockatong contact, shows the interpreted flow direction of the Palisades magma. The exposure is immediately north of the George Washington Bridge on the Palisades Interstate Park access road in Fort Lee, New Jersey. Knife (scale) is 9 cm in length. (CM photograph).

Paleoflow direction of the Palisades magma. For the Newark Basin segment, many investigators have suggested that the Palisades magma flowed outward from buried fractures paralleling the NE-SW-trending Ramapo fault zone. To reach Fort Lee, New Jersey and vicinity, magma from such fractures would have to have flowed from NW to SE. In Fort Lee, beneath the George Washington Bridge (Stop 1 for today's trip), xenoliths, screens, and in-situ laminated lacustrine Lockatong sedimentary strata (black argillite and interlayered buff-colored feldspathic sandstone) have been contact metamorphosed and deformed. Here, the basal contact of the Palisades sheet cuts across the bedding in a ramp-like fashion toward the north. Similar contact relationships for the Palisades are exposed near Bergen and at King's Bluff, both farther south in New Jersey. (See Figure 19.) Folded xenoliths and folds of Lockatong sedimentary strata at the igneous contacts are products of subhorizontal shear. Their steep- to overturned axial surfaces trend E-W and are vertical or dip southward. Together, these marginal relationships suggest the general paleoflow of the magma was from SW to NE.

A Possible Feeder Area, Graniteville Quarry, Staten Island, New York. Examination of the orientations- and marginal relationships of xenoliths in the Palisades of New York and New Jersey has helped us identify a possible feeder area for the intrusive sheet. At Graniteville, Staten Island [Elizabeth quadrangle boundary; UTM coordinates: 571.60E - 4497.72N], a curved, partially fused, Lockatong xenolith is vertical and largely surrounded by concentrically oriented annular joints. Studies here by Benimoff and Sclar (1984, 1988), offer proof that a xenolith of the Lockatong Formation (formerly considered to be a small dike intruding the dolerite) was not only internally altered by the heat from the surrounding mafic magma, but that some of the Lockatong actually melted in situ to produce a trondhjemitic magma. We have suggested (Merguerian and Sanders, 1992, 1994b) that such intense melting may have been caused by a continuous heat source, perhaps emanating from an area of active magmatic flow. Furthermore, we have suggested that the annular joint pattern may mimic paleoisothermal cooling surfaces.

By contrast, most xenoliths reported from the New York City area dip gently and are oriented parallel to the contacts of the Palisades intrusive sheet. At Graniteville, a fused vertical xenolith and the annular cooling(?) joints imply that the magma here flowed upward and thus is close to a steeply inclined feeder channel. Geological relationships described above from Fort Lee, Bergen, and King's Bluff, New Jersey suggest that internal flow of the magma in those areas (See Figure 5.) was directed northeastward, perhaps away from Graniteville. If this is correct, then from Staten Island to Fort Lee, the lateral paleoflow pattern would have been from SW to NE. In support of this model we note that the Palisades intrusive is thickest and at its lowest stratigraphic position in the vicinity of New York City and that the body progressively thins as it migrates up section to the northeast (toward Haverstraw) and to the southwest (into the Delaware Subbasin). (See Figure 16.) Thus, our proposal for magmatic paleoflow toward the NE is consistent with evidence from the quarry at Graniteville, Staten Island.

"Sedimentary Apophyses" and Syn-intrusive Clastic Dikes. In Fort Lee, the Lockatong contains many sandy interbeds of light-colored feldspathic sandstones of typical "Stockton"-type lithology. Although the sandy layers have been less obviously affected by contact metamorphism than have the argillites, near the contact the sands are chaotic. They contain small, angular xenoliths of thermally altered argillite and have been locally "intruded" upward to crosscut baked Lockatong as wispy irregular "sedimentary apophyses" up to 20 cm long (Figure 22). Elsewhere, an irregular "stock-like" mass of feldspathic sediment more than 0.5 m thick, which encloses angular-, brecciated chunks of chilled basalt, exhibits several elongated drusy cavities that resemble miarolitic cavities of igneous rocks.

Figure 22. View of a feldspathic sand "apophyse" intruded upward, beyond level of hammer, from contact-metamorphosed Lockatong into chilled Palisades basalt. The hammer handle is 40 cm in length and rests on the basal contact of the Palisades chilled-margin basalt. (CM photograph.)

More commonly, thin light-colored clastic dikes with sharp contacts project into the Palisades chilled zone (Figure 23). We have found more than a dozen examples of the thin, continuous light-colored "dikes" of clastic sandy sedimentary material crosscutting the chilled contact rocks. In marked contrast to their parent sedimentary sources, they are totally nondeformed. Their thicknesses vary from 0.5 cm to a few cms, and their lengths, vary from a few cm to more than a meter. Bifurcating dikes have been observed. These field relationships suggest that the clastic dikes, consisting of formerly fluidized bodies of sand, were intruded upward after the marginal magma had experienced an initial phase of chilling during diminished magmatic flow. The drusy cavities, together with the basalt microvesicles and pipe amygdales noted earlier, support the view that the clastic-dike materials included a vapor phase. We surmise that the bounding sediments still contained pore water before the cooling Palisades magma heated them. Thus, we envision that the sandy injections and dikes represent tongues of hot, fluidized cohesionless sand that were driven by pore waters in the Lockatong and its sandy interlayers that had been vaporized by magmatic heat. In the following and in the description for Stop 1, we outline the field- and petrographic data on which our inference that the Palisades sheet was intruded at a shallow depth of burial is based.

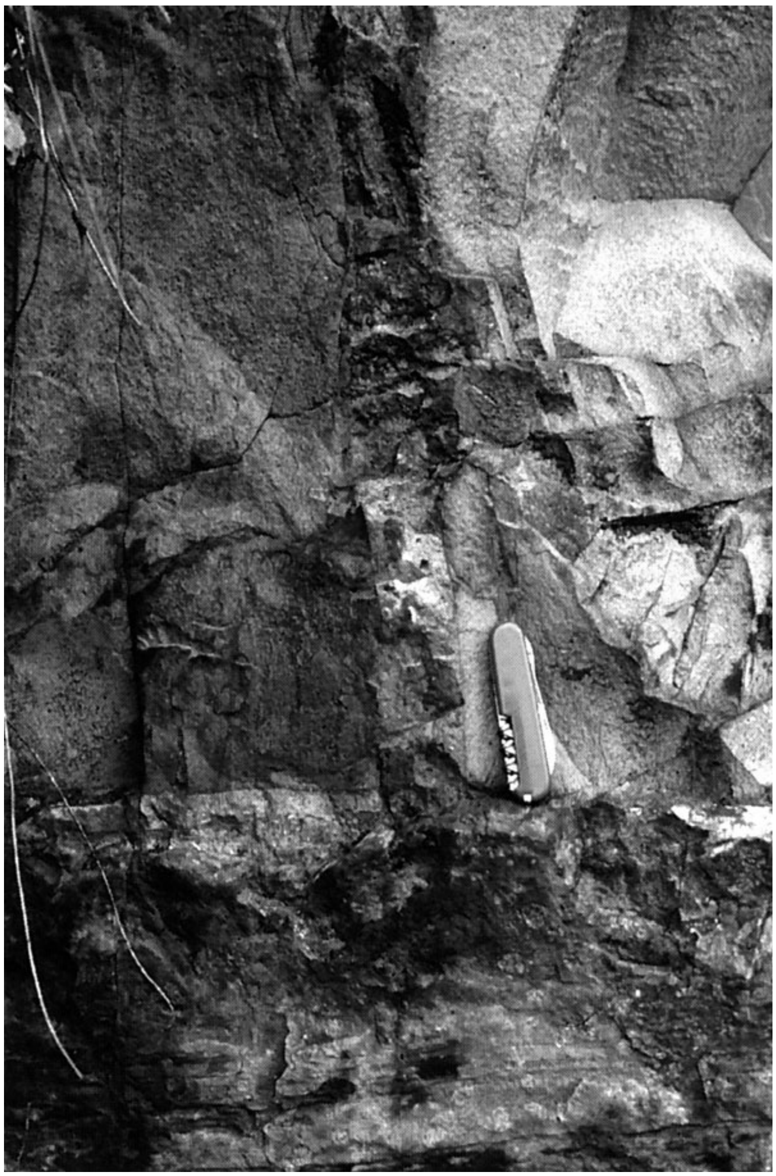


Figure 23. View of a 3-cm-thick feldspathic "clastic dike" that has intruded the Palisades chilled margin. Knife (scale) is 9 cm in length. (CM photograph.)

Petrography of the Clastic Dikes. Microscopic study of thin sections of representative samples indicates that the light-colored dikes are composed of thermally altered detrital sediments consisting predominantly of subangular feldspathic sand-size particles. Use of the microscope discloses [Sample PAL-5] altered, contact-metamorphosed remnant clastic textures within the "clastic dikes" with subrounded K-feldspar, plagioclase, and quartz exhibiting pronounced monomineralic overgrowths. The feldspars are clouded and show dominantly granoblastic boundaries, which together with the overall felsic mineral components, may have convinced Walker (1969) to suggest that the light-colored dikes ["rheomorphic veins" of his usage] were of igneous origin. Microscopically, the feldspar particles are clastic; some contain subrounded cores and others preserve rounded boundary edges. As such, we suggest that the granoblastic textures are the result of contact-metamorphic- induced recrystallization. Additional detrital components in the clastic dikes include basalt fragments and other lithic fragments including argillite and chert(?).

Another thin section of a clastic dike [Sample PAL-2] shows that near the contact with basalt, sizes of detrital particles increase and also that elongate quartz, K-feldspar, plagioclase, and lithic fragments have been aligned parallel to the margin. In the interior of the dike, many well-rounded quartz- and relatively fresh feldpar particles are present. We interpret that the aligned fabric of elongate particles parallel to the dike margins resulted from a dynamic flow orientation similar to that found in clastic dikes in the sedimentary realm. At the dike contact, the basalt displays a bleached zone. We interpret the coarser texture at the dike contact with basalt as being the result of localized recrystallization and metasomatism; the chilled basalt margin may have still been hot.

Lithification State of the Bounding Sediments at Time of Intrusion. Our efforts, which have focused on the basal contact relationships of the Palisades intrusive, place constraints not only on the paleoflow direction of the magma but also upon the state of lithification of the bounding sediments when the magma appeard. Using evidence about the latter, we have made a new estimate (discussion below) on the depth of intrusion of the Palisades magma(s). In the following we focus on the field evidence that at the time of intrusion, the Newarkian sediments had not yet become lithified. We describe late syn-tectonic clastic dikes, and suggest an approximate depth of intrusion.

Cooling-depth Model. The presence of clastic dikes and vesiculated features in the base of the Palisades suggests that, in the vicinity of New York City, Palisades magma was intruded into Lockatong sediments that had not been buried deep enough so that they had become totally dewatering and lithified. Rather, we suspect that upon being heated by the magma in the chilled margin of the Palisades sheet, the water-bearing sediments became vapor-charged-, fluidized bodies of cohesionless sand. The fact that columnar joints penetrate the Palisades intrusive, the clastic dikes, and Lockatong xenoliths, indicates that the clastic dikes were injected quite early in the solidification history of the Palisades igneous rock.

An analogous situation, from a quarry in West Rock in New Haven, CT, in the Hartford Basin, was reported by Walton and O'Sullivan (1950). There, a layer of conglomeratic arkose produced a branching, irregular clastic dike exhibiting sharp contacts which was intruded upward more than 10 m into the dolerite sill. The dike consists of detrital material derived from the underlying conglomerate including several large pebbles, one of which was transported 0.6 m above the base of the sill. According to Walton and O'Sullivan, the clastic dikes were intruded at a temperature of roughly 400°C and a pressure of 0.4 Kb. We suggest similar conditions for our observed features and would argue, based on a simple stratigraphic calculation (below), that the depth of intrusion for the Palisades was in the range of 3 to 4 km.

As noted above, the Newark mafic igneous rocks include both intrusives (the Palisades mafic intrusive sheet) and extrusives (forming the three "Watchung" basalt sheets in the Watchung syncline and several scattered areas along the Ramapo fault and elsewhere). A recurrent subject of interest among igneous geologists has been proof of consanguinity between the Watchung extrusives and phases of the Palisades intrusive. The Palisades mafic sheet was intruded into the base of the Newark Supergroup during the Sinemurian age of the Early Jurassic (roughly 201 ñ1 Ma) according to recent U/Pb data on Palisades zircon and baddeleyite by Dunning and Hodych (1990). These data conform with Sutter's (1988) 40Ar/39Ar dating, which has yielded a 202.2 +/-1.3 Ma age for a fused xenolith of Stockton arkose within the Palisades.

An important point to be established about the Palisades intrusive is the timing of the intrusion relative to extrusion of one or more of the Watchung extrusive sheets. According to petrographic studies and modal calculations of Sichko (1970 ms.) and geochemical studies of Puffer (1988) and Husch (1990), a likely correlation is between the high-Ti magma that solidified to form the Palisades and the various lavas that cooled to form the multiple flows of the Orange Mountain Formation (First Watchung Basalt). Husch (1990) also correlated a low-Ti magma component of the Palisades with the upper low-Ti flow unit of the Preakness Formation (Second Watchung Basalt).

Based on their interpretation of the duration of deposition under the influence of climate cycles in the associated sedimentary strata, Olsen and Fedosh (1988) calculated that approximately 2.5 Ma elapsed between the time of extrusion of the Orange Mountain Formation and that of the Preakness Formation. This means that if igneous activity within the Palisades took place at the same time as that of the extrusion of these two ancient lava flows, then more than 2.5 Ma were available for the composite Palisades intrusive sheet to cool. The general absence of chilled zones within the main mass of the Palisades intrusive implies that all pulses of magmatic activity took place in a short time interval, before the mafic intrusive had cooled.

The synchroneity of intrusion of the Palisades with one or more of the Watchung flows also settles a further point, the depth of intrusion. Depth of intrusion then is the stratigraphic thickness of Newark strata between the base of the oldest Watchung flow and the base of the Palisades sheet. Using an outcrop-belt map distance of 18 km between the base of the Palisades and the base of the Orange Mountain Basalt and an average dip of 12.5°, the stratigraphic thickness would equate to [Sine 12.5° (0.2164) X 18 km = 3.89 km]. A 10°-dip assumption would decrease the estimate to 3.12 km. A 15°-dip assumption would increase the estimate to 4.65 km.

Extrusive Sheets. When the sheets of igneous rock were first studied in New Jersey, they were all thought to be of intrusive origin (I. C. Russell, 1877). As long as the sheets of mafic igneous rocks were considered to be intrusives, no special stratigraphic- or structural value could be attached to them. We review the proof of their extrusive orign, use in geologic mapping, and relationships to folds and faults.

Proof of Origin. The question of the origin of these sheets of igneous rock intercalated among the Newark sedimentary strata became a major issue when William Morris Davis, then a young instructor at Harvard, showed that the units shown as the "Anterior," "Main," and "Posterior" trap sheets on the first state geologic map of Connecticut (Percival, 1842) are extrusives. Given an extrusive origin, these sheets of igneous rock could be considered as part of the stratal succession just as if they were distinctive sandstones, for example. Better still, they could be interpreted as time-stratigraphic deposits related to an episodic geologic event!

Use in Geologic Mapping. Davis and his students redrew the geologic map of the area underlain by the Newark strata in central Connecticut. They used the extrusive sheets to analyze the structure of the Newark strata of the Connecticut Valley belt (now the Hartford basin), and thus could make a major advance over the Percival's (1842) outcrop map. As a result, Davis became the father of the stratigraphy of volcanic rocks. (See Davis 1882a, 1882b, 1883, 1886, 1888a, b, 1889a, 1896, and 1898; Davis and Whittle, 1889.)

Building on Davis' results and using the time-stratigraphic significance of the extrusive sheets, W. L. Russell (1922) showed that rapid facies changes in the strata interbedded with the extrusive sheets could be demonstrated in southern Connecticut merely by walking out the basal contacts of these sheets of igneous rock and by observing how the particle sizes changed from boulder conglomerates close to the basin-marginal fault to mudstones a few kilometers distant from the basin-marginal fault.

Relationship to Folds and Faults. The fact that the outcrop belts of the resistant sheets of mafic rocks are not straight but curved demonstrates that the interpretation of the geologic structure as a simple homocline (as along the vertical face across the middle of Figures 1 and 3), is not accurate. Instead of being strictly linear, as would be the eroded edges of resistant strata in a true homocline, the ridges that are underlain by the sheets of extrusive igneous rock are curvilinear. Their pattern is more like that of a group of offset letter "C's" instead of "I's" as in a simple homocline. This curvilinear pattern has resulted from the erosion of a series of folds whose axial planes are perpendicular to the basin-marginal fault. Accordingly, JES has classified these folds as being transverse folds. (See detailed discussion in Merguerian and Sanders, 1991c; 1994.)

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

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

One of the problems that has nagged at JES during the last 30 years is what one has to do in order to get the self-appointed "high priests" of plate tectonics to understand that the Newark strata imply a complex history which is not adequately interpreted by the "simple-tension" interpretation that has come to prevail. As far as JES can discern, the basis for this prevailing interpretation, which holds that the origin of the Newark strata is closely related to the beginning of the current Atlantic spreading cycle, rests entirely on a series of repeated assertions and is best regarded as a case of geologic incest.

In order to try to deal conclusively with the connection between the Newark strata and concepts of plate tectonics, we first summarize the history of some intellectual battles about the Newark strata. After that, we summarize the tectonic history, emphasizing arguments in favor of the concept that the correct tectonic history of the Newark involves more than simple tension. In fact, we regard these simple explanations as a major cause for tension headaches. Finally, we point out how the Newark Group, shorn of its "simple-tension syndrome," offers a splendid example of how plate-tectonic concepts can be applied to understanding the Newark strata. In a nutshell, our view is that the origin of the Newark strata and their deformation entirely preceded the opening of the Atlantic Ocean. In short, we shall try to make the case that the Newark chapter had been completed before that Atlantic chapter began.

HISTORY OF SOME INTELLECTUAL BATTLES OVER THE NEWARK STRATA

In this section, we review some of the intellectual battles that have been waged over the Newark strata. A look back at such battles sometimes proves to be very interesting. A thumbnail sketch of what they are all about might go something like this. Someone makes an observation and draws a conclusion from it. At this point, one of two paths might be followed. If the existing mental state of the time will accommodate the conclusion, then it is likely to be built upon, to stimulate further work and science "progresses." If the existing mental state of the time will not accept the conclusion, then an elaborate web of rationalization may be spun to build an intellectual "house of cards" on some basis other than the unacceptable conclusion. In either event, the end product may be a beautiful intellectual construct. Time and time again, the foundation on which such a beautiful intellectual construct has been built is destroyed. This may happen because new data become available or whatever. The new data absolutely destroy the foundation of the older "houses of cards." At such times, a shakeup of thinking takes place. Logic dictates that this shakeup should include the total abandonment of all "houses of cards" built on the destroyed foundation. But how many times does this not happen? Instead, one sees that great ingenuity is expended on trying to retain the beautiful "house of cards." JES refers to this tendency as "the persistence of ideas lacking visible means of support."

This review includes examples of what we consider to be three examples of geologic "houses of cards" about the Newark.

(1) **House of cards No. 1** goes by the title of the Topsy or cabbage-bush "house," so named from that legendary character of the children's book "Br'er Rabbit," Topsy, who "just growed." Among the early students of the Newark strata, the two chief "cabbage-patch kids" were the distinguished Rogers brothers, Henry D. and William B. These two were truly giants of nineteenth-century American geology. They are justly famous for their remarkable geologic insights into the folded structure of the Appalachians.

(2) **House of cards No. 2** goes by the name of "the great Appalachian tranquilizer," or the "tension syndrome." We use this name with reference to the widely believed notion that one should consider the Newark as a kind of Appalachian afterthought, a product of the great crustal relaxation that logically followed after the great prolonged epic of Appalachian orogenic crustal compression. Not only did geologists find this concept of crustal relaxation easy medicine to swallow but they enjoyed it all the more because it also allowed them to relax their brains on the subject and to be happy with the notion that as far as the Newark was concerned, they had "learned it all in kindergarten." Thus, they needed to ask no further questions and all was quiet on the eastern front.

(3) **House of cards No. 3** marches under the banner of "Atlantis" or "stretchini." It comes closer to the present day: it is the product of the quick-fix transplant based on the tension syndrome of the Newark from the second- or Appalachian "house of cards." In this scheme, the Newark strata were yanked loose from the Appalachians and relocated within the Atlantic cycle. The basis for this change was the tension-syndrome view of the Newark. As such, the Newark strata were considered to be the logical products of the tension and stretching involved in the opening of the Atlantic Ocean.

With this somewhat facetious, if not long-winded, preamble out of the way, let us now take a look at what serious-minded geologists have written about the Newark strata. After you have read the reviews of each episode, ask yourself three questions about the aftermath of such intellectual shakeouts: (1) What survived? (2) What was discarded? and (3) What was forgotten?

One result of even a cursory examination of the voluminous literature on the Newark strata, is to leave the reader with the overriding impression that nineteenth-century geologists felt heavy constraints with respect to both space and time. Accordingly, some of them seemed to have recoiled from the conclusions that arose from the straightforward geologic implications of the Newark strata. Time after time, one reads expressions that might be somewhat freely rendered by: "the Newark strata just can't possibly be that thick," (as calculated from average dip and width of outcrop), or "the strikes and dips don't mean anything in the way of tectonics; the only tectonic events that affected the Newark strata were a bit of tensional collapsing and rotation of fault blocks after the Appalachian deformation."

The following paragraphs review, under the possibly frivilous, but nonetheless serious, categories, some major points in the intellectual history of the Newark strata.

The "Topsy" School (the "Cabbage-patch" Kids, the Rogers Brothers)

To get to some specifics, consider the remarks made by one of the early giants of American geology, H. D. Rogers, with reference to the stratigraphic thickness that one can calculate by following the proposition that the Newark strata in central New Jersey had been deposited initially in a horizontal position and afterwards deformed. Based on application of the usual geologic procedure with respect to a thickness calculation of inclined strata, the result prompted Rogers to write (and to reiterate verbatim several times) that the answer is:

"beyond all precedent among stratified formations" (H. D. Rogers, 1840, p. 167; 1865, p. 126).

Well, when one sees a supposedly "unacceptable" result looming up out of one's observations and calculations, what does one do to "bury" the problem? Several alternatives seem to have been tried, but at the top of the JES list of ingenious attempts to "explain away" the uncomfortable implications about the thickness of the Newark strata is the line of thought proposed by H. D. Rogers in his hypothesis of "estuarine currents." By applying this hypothesis, Rogers satisfied himself not only that no problem of great stratigraphic thickness existed, but further that no tectonic activity was needed to explain the observed dips. According to Rogers, the strata of the Newark-Gettysburg basin in the New York-New Jersey-Pennsylvania Newark outcrop belt had been deposited in an elongate narrow estuary whose geographic extent coincided with the preserved limit of Newark strata. Within this estuary, the water currents had flowed diagonally across the long axis, moving generally from the south and southeast to the north and northwest. Rogers held that the effects of these supposed currents could be found in the strata

"producing an almost universal dip of the beds toward the northwest, a feature clearly not caused by any uplifting agency, but assumed originally at the time of their deposition, in consequence of the setting of the current from the opposite or southeastern shore"
(H. D. Rogers, 1839, p. 20; 1840, p. 115; 1865, p. 86).

By the following remarks, we mean no disrespect to the great Rogers brothers. The point to be illustrated is that geologists (as well as most other people) will go to extreme lengths to lay aside unsettling lines of thought. (Psychologists call this "denial.") How better to put the Newark strata aside altogether than to adopt the Rogers' concept--a concept that we regard as the ultimate in trivializing the Newark strata. The beauty of the Rogers' scheme was that in it, the Newark strata "just happened." This is the basis for the name of the Topsy school of thought. In the manner of Topsy, the Rogers brothers thought that the Newark strata were something that "just growed;" thus, these strata could be considered as something one might just find under a cabbage plant. Gone were any worries about syndepositional subsidence (to apply a couple of twentieth-century words). What is more, zero postdepositional tectonic movements were needed. The Newark strata sprang full blown from Mother Nature's womb.

As powerful as were the Rogers brothers, and as honored and revered as they were as a consequence of their remarkable insights into the large-scale folded structure of the Appalachians, they did not succeed in persuading many of their colleagues to adopt their "under-the-cabbage-bush" approach to the Newark. They did enlist Whelpley (1845) and Whitney (1860) in the Connecticut Valley belt (now referred to as the Hartford basin), and Frazer (1883) in Pennsylvania, all of whom openly advocated variations of the Rogers initial-dip scheme. To the contrary, many nineteenth-century geologists amassed an impressive case in opposition to the initial-dip hypothesis. They built their opposing case by appealing to the evidence contained in primary sedimentary structures. In so doing, they presented the first example we know of in which geologists in the United States used primary sedimentary structures as compelling evidence to settle a significant geologic problem (Sanders, 1978, p. 681). As that gnarled old man of baseball, Casey Stengel, used to say: "You could look it up." If you want to, try Redfield (1843); Edward Hitchcock (1853, 1858); I. C. Russell (1878); W. M. Davis (1882a,b; and later papers): G. H. Cook (1882, 1887); B. S. Lyman (1894, 1895); and N. H. Darton (1909).

The amount- and quality of the geologic evidence that these and other geologists marshalled against the Rogers brothers' interpretation was overwhelming. A great intellectual battle had been fought and won by those opposed to the cabbage-patch interpretation. But, as a result of this battle and the associated shakeout of ideas, what concepts carried on? Is the outcome of this battle remembered by the triumphs of the use of primary sedimentary structures? Or by W. M. Davis' use of extrusives for mapping stratified rocks (i.e., the establishment of the important subdiscipline of the stratigraphy of volcanic rocks)? JES argues that the surviving tradition, the carryover from this episode, was rather the trivialization of the Newark. The idea of initial dip as gigantic cross strata seems to have been discarded. The notion that the environment of deposition had been as estuary survived for some years later, but has been totally refuted. And, those two fundamental bases on which the intellectual victory depended, (a) the use of primary sedimentary structures and (b) the establishment of the stratigraphy of volcanic rocks were generally forgotten. In other words, JES contends that the effect of the intellectual shakeout of this crucial intellectual battle was to provide example No. 1 of the persistence of a Newark idea lacking visible means of support.

Foundations of Modern Concepts: Mapping Leads to "the Great Appalachian Tranquilizer" (and the "Tension Syndrome")

Starting late in the nineteenth century, a new generation of geologists began to study and to map the Newark strata in Pennsylvania (B. S. Lyman, 1894, 1895) and in New Jersey-New York (H. B. Kummel, 1897; 1898a, b; 1899a, b). Not only did these gentlemen establish the basic stratigraphic framework some of which is still in use today, but they demonstrated without any doubt that the Newark strata, originally horizontal, had been variously bent into their present attitudes and also had been cut by many faults. The maps which they prepared demonstrated that locally within the Newark outcrop belts, folds are present. As far as JES is aware, the first geologist to mention folds in the Newark strata was N. H. Darton (1890). Nearly everyone else either ignored these mapped folds, or at most, mentioned the folds only briefly. The tendency was to pass off the folds as being of negligible tectonic significance. In some cases, geologists made casual references to the folds as products of "local warping." Such warping is a logical expectation in strata that have been tilted and faulted. In general, no geologist seemed willing to face up to what their maps were trying to tell them. As a result, the folded Newark strata offer another example of shades being drawn across the visions of geologists who worked on the Newark rocks.

This brings us to the next milestone in the "putting down" of the Newark strata. This time, the put-down results were much more far reaching and more widely adopted than in the case of the Topsy school of thought. Referred to here is the interpretation that the Newark strata represent a kind of ho-hum postcript to the Appalachian deformation--nothing more than a bit of tension, as it were, after the great compressional display of the Appalachian orogenic climax. Not only was it fashionable to think that the Earth's crust in the Appalachian region had relaxed but also that geologists' brains could relax and need not do any serious worrying or thinking about the regional implications of the Newark strata.

As far as JES is concerned, the new generation of geologic maps referred to above utterly, totally, and completely destroys the basis for the simple-tension interpretation of the Newark strata. JES claims no personal credit for this destruction. At most, he has simply assembled and repeated a couple of times in published articles what he regards as being so obvious and self evident that it scarcely merits further discussion. The evidence is contained in papers and maps of Darton (1890); W. L. Russell (1922); Girard Wheeler (1939); and C. R. Longwell (1928). But, ask yourselves: "Have these classic papers from the earlier literature or the several JES attempts to show the excellence of these earlier works dispelled the "tension syndrome?" Quite the contrary; JES submits that continued acceptance of the tenets of the "tension syndrome" serves as a second- and splendid example based on the Newark strata of the "persistence of an idea lacking visible means of support."

Plate Tectonics to the Rescue? "Atlantis" and "Stretchini" Appear

Starting in the mid-1960s, when the great new vistas of plate tectonics were unfolding within the geologic world, JES thought: "At last, a suitable framework for understanding the Newark strata has appeared. Now, everyone will get it right. JES can stop trying to convince anybody about the complexity of the Newark. Their expanded new outlook will cause them to throw away the blinders and see what the rocks have to say." In case you need further help in comprehending this remark, it might be evaluated by a Foghorn Leghorn comment: "That's a joke, son."

What does the plate-tectonic literature contain about the Newark strata? The same only phony baloney of tension all wrapped up in some new words about the opening of the Atlantic Ocean. At first thought, what could be more logical? The growing Atlantic Ocean involves tension and spreading. So far, so good. What else might involve tension? Oh, yes, the Newark strata. Great! Just put the two together where they belong.

JES has not tracked through all the plate-tectonic literature to count the number of times the coupling of the Newark-tension concept with the opening of the Atlantic Ocean has appeared in print since it was first published as an offhand remark that the date of beginning of the formation of the North American continental margin was Late in the Triassic Period (cited by Dewey and Bird, 1970, p. 2630, as a personal communication with Walter Pitman). Dewey and Bird's paper includes the following:

"It is suggested that much of the locally thick accumulation of sediment was deposited on graben that formed during the earliest stages of continental rifting during late Triassic times.

This is supported by the presence of late Triassic volcanics and coarse red clastics in the Bay of Fundy, Connecticut, and the Newark graben" *(p. 2633).*

In a companion paper, Bird and Dewey wrote:

"Post-Acadian deformation of the Appalachian Orogen, the Alleghenian folding and Triassic block faulting, are believed by the authors to be related to the initial stages of opening of the present Atlantic Ocean (Dewey and Bird, in press). Subsequently, due to extensional necking, the Triassic fault troughs formed, followed by the establishment of the present continental margin (sic) sediment assemblage during the course of opening of the present Atlantic Ocean" *(Bird and Dewey, 1970, p. 1051).*

Only Falvey (1974) seems to present new insights about how the Newark strata might be comprehended in terms of the development of a passive continental margin. Nearly all others seem to have been guilty of repeating an assertion and thus of giving credence by mere repetition. JES offers the plate-tectonic mumbo-jumbo about Newark tension and the opening of the Atlantic Ocean as being the third example of persistence without visible means of support of an idea about the Newark strata.

At this point we turn to the labyrinthine topic of the tectonic history of the Newark strata.

TECTONIC HISTORY OF THE NEWARK STRATA

Nearly all currently fashionable interpretations about the Newark strata begin with the phrase "rift basin." Such basins are diagnostic features of extensional tectonics. With respect to the Newark basin, the concept of rift tectonics has been refined slightly by including the notion of "reactivation tectonics." And, now we are beginning to hear words like "inversion tectonics." And, praise be! "compression" and "folding." In the following sections, we try to explain these modern tectonic concepts. After that, we evaluate them as applied to the Newark basin.

Extensional Tectonics; Rift Basins

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

The fundamental features of extensional tectonics are listric normal faults that are steep at the Earth's surface, but that curve around to a horizontal orientation at a depth of 15 km or so, where the rheological properties of the lithosphere change from brittle to ductile (Figure 24). The normal faults in the extensional network do not extend laterally along the Earth's surface for great distances; they die out. Beyond where one fault ends, another may appear. In between is a relay ramp (Figure 25).

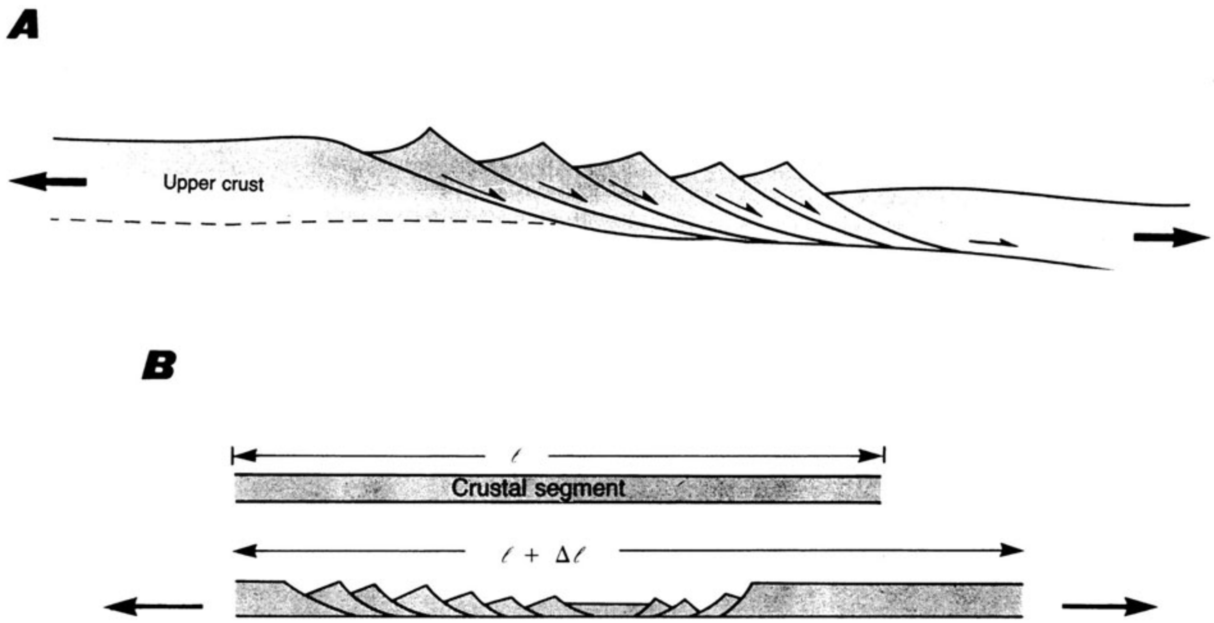


Figure 24. Profile section; steep brittle faults propagating downard, curving, and becoming horizontal at depth in the brittle-ductile transition zone. (R. D. Hatcher, Jr., 1990, A, fig. 10-15 (c), p. 190; and B fig.13-8 (c), p. 261.)

A. All faults curve in the same sense.

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

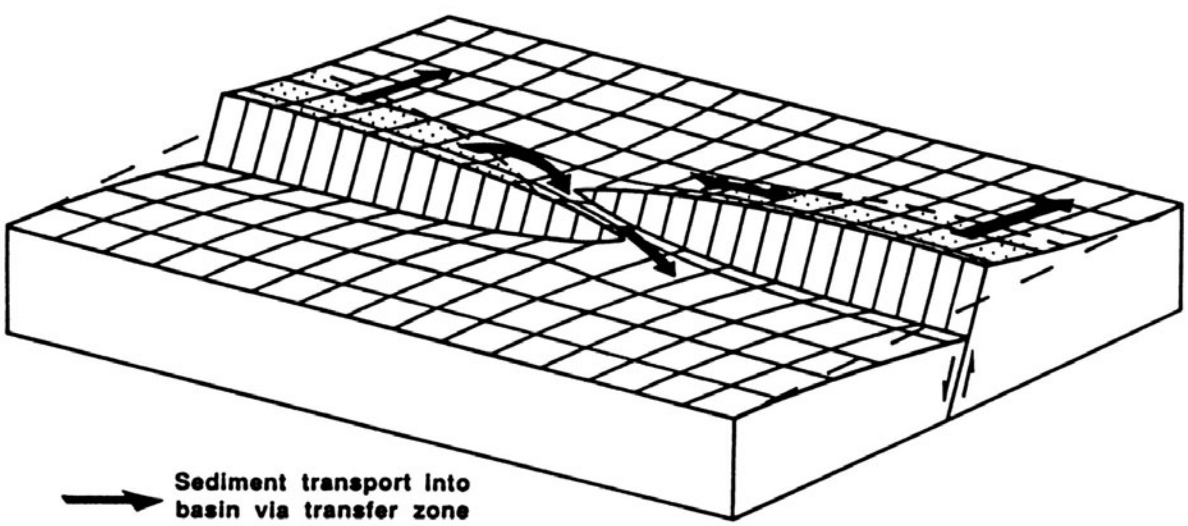


Figure 25. Schematic block diagram viewed diagonally from above showing two normal faults that are offset en ,chelon and separated by a relay ramp (=transfer zone). Black arrows on top of diagram indicate major transport directions of sediment on upthrown block. On the downthrown block, coarser synrift sediments accumulate near the ramp. (A. Roberts and G. Yielding, 1994, fig. 11.19, p. 242.)

Displacement on the curved surfaces of listric normal faults causes the formerly horizontal surface of the Earth moving downward along the fault to dip toward the fault (Figure 26). Because the angle between the fault and the surface is fixed by the relationships at the surface, as further displacement on the curved fault surface takes place, the top of the downshifted block becomes tilted to ever-steeper angles.

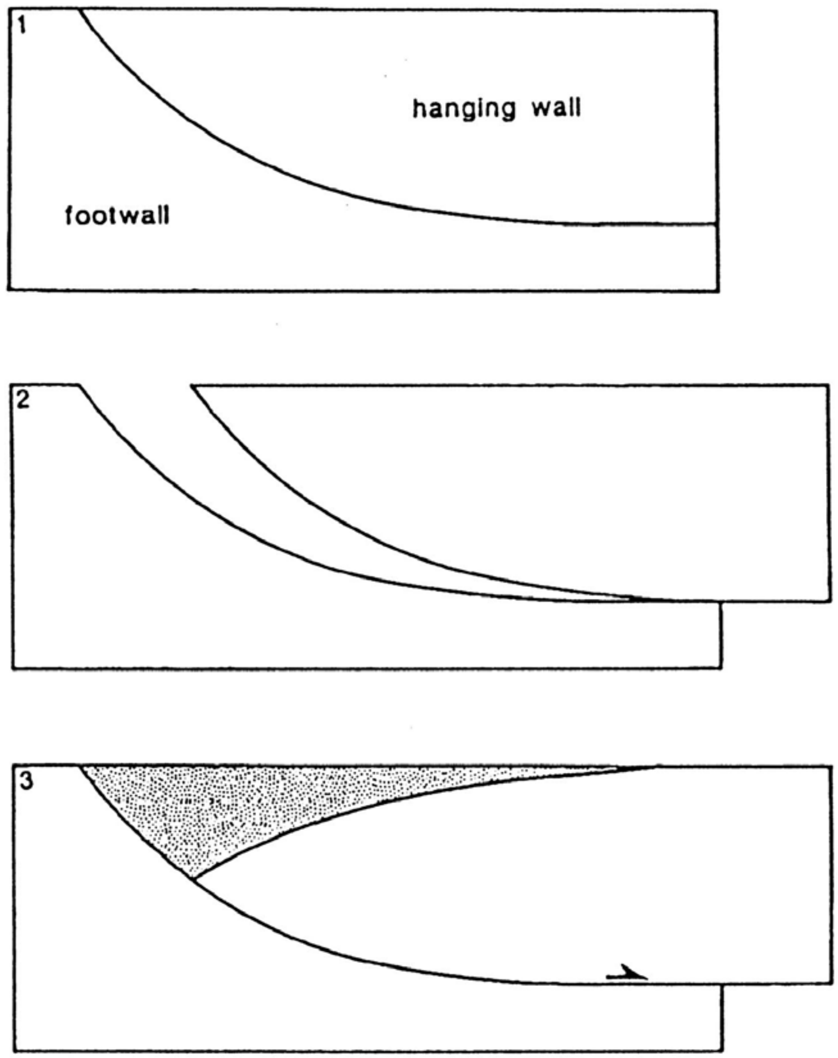


Figure 26. Wedge-shaped basin (stippled) formed by movement of a crustal block along a listric normal fault. Progressive movement causes the initially horizontal land surface to be bent downward to maintain the constant angle between the fault and the land surface (where the fault is steep) as the surface moves along the curved fault surface. (J. M. Crespi, 1988, fig. 1, p. 221.)

The mechanism shown in Figure 26 could cause a basin to form and to fill with sediment. Moreover, cessation of the movement on the fault would stop all the activity. When movement on the fault stopped, many strata, which were initially deposited in a horizontal orientation, would dip toward the fault. The amount of this dip would be greatest in the oldest strata and would progressively diminish to zero in the youngest beds.

JES considers that application of this concept to the Newark basin can be classified as nothing more than a modern-day variation of the "cabbage-patch" approach to the Newark. It is an up-to-date tectonic version of H. D. Rogers' depositional scheme whereby the tilted strata are initial dips; no postdepositional tilting is required. (Many of the ideas such as this have been proposed by workers who have seen the deep seismic-reflection profiles which may show in the subsurface of the Newark basin features such as those shown in Figure 27. JES has not seen any continuous seismic-reflection profiles from the Newark basin, so his thinking is based on outcrop data only.)

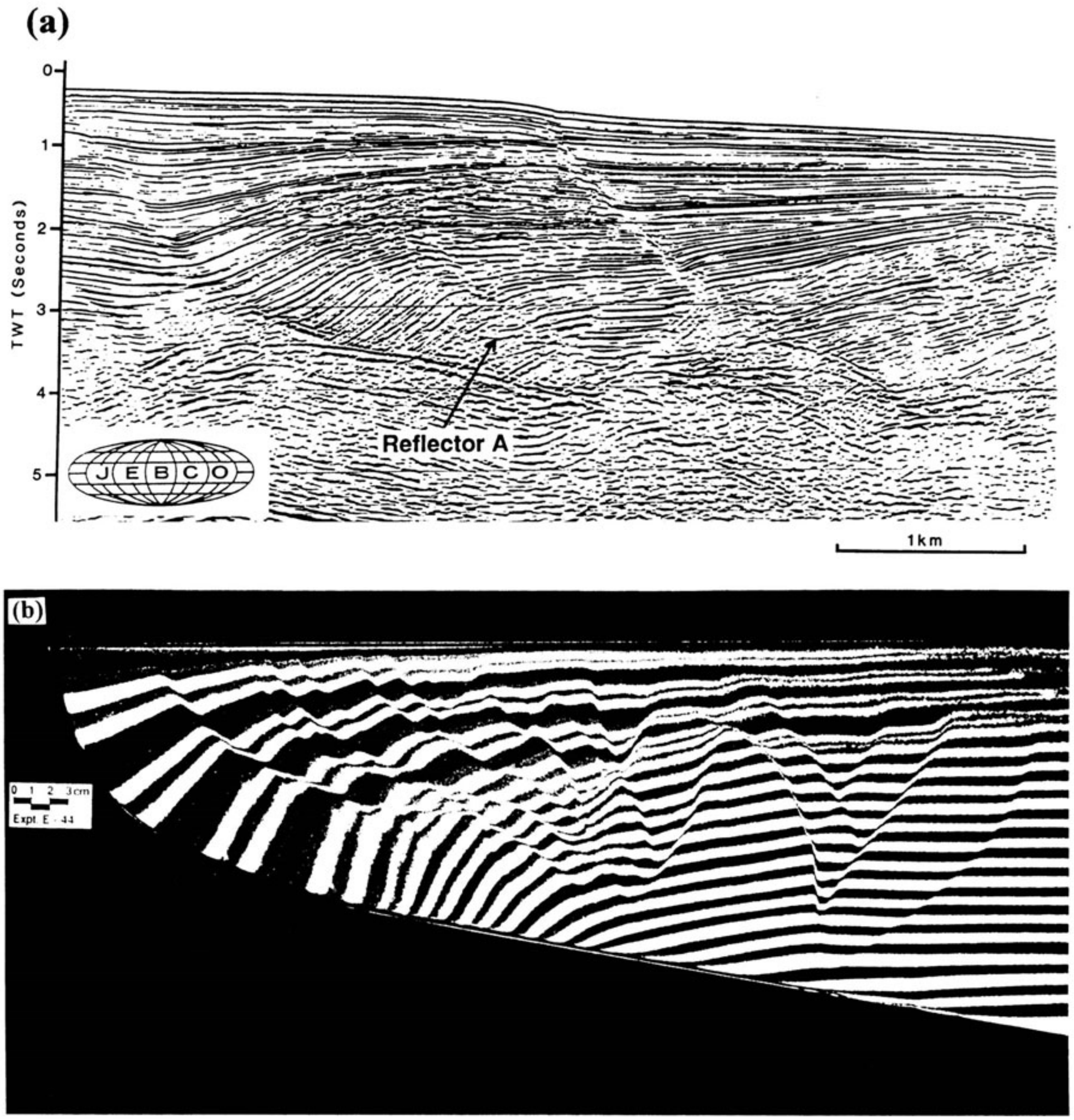


Figure 27. Effects on strata of upper block as a result of displacement along a curving normal fault. The angle between fault and strata remains constant. As the strata move downward and the fault curves, they dip toward the fault.
(a) Continuous seismic-reflection profile in Gulf of Mexico.
(b) View of sand-box model with rigid footwall block. (A. Roberts and G. Yielding, 1994, fig. 11.20, p. 243.)

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

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

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

Reactivation Tectonics

The concept of reactivation tectonics is based on the proposition that younger faults follow older faults; in the younger tectonic episode, older faults are reactivated. In the case of the Newark basin-marginal fault, deep continuous seismic-reflection profiles show that at depth, the reflector trace of this fault is the same as that from an Early Paleozoic thrust (Ratcliffe and Burton, 1985; Ratcliffe, Burton, D'Angelo, and Costain, 1986).

A not-so-subtle "hidden agenda" lurking behind this emphasis on the coincidence between Newark-age faults and pre-Newark faults can be expressed as follows: the Newark faults followed pre-existing zones of weakness, therefore, no post-Newark structural complexity needs be inferred, and thus let the long-standing "Ho-hum" attitude about the Newark continue to prevail. (See, for example, Lindholm, 1978b; Petersen and others, 1984.)
Ratcliffe and Burton (1985; 1988) and Ratcliffe, Burton, D'Angelo, and Costain (1986) have emphasized the results from continuous seismic-reflection profiles that show the Newark basin-marginal faults following Paleozoic mylonite zones that formed along regional thrusts.

Inversion Tectonics

By inversion tectonics is meant the activities that cause the strata in a rift basin to be deformed by postdepositional compression. The basic concept has grown out of continuous-seismic-reflection profiles that show a change from sediment accumulation in a basin to sediment deformation as a result of later activities. (For example, see Cooper, 1989; Hayward and Graham, 1989; Manspeizer, 1994; Manspeizer and Gates, 1995; McClay and Buchanan, 1992; and Schlische, 1995). What are the products of inversion to some are just plain old-fashioned folds and thrusts--the results of compression to others.

Strike-slip Tectonics: Pull-apart Basins

The concepts of strike-slip tectonics have developed mainly from studies along the San Andreas fault system in California. Within a complex zone where strike-slip motion is taking place are three zones: (1) a zone of extension (which could produce "normal" faults, small basins formed by such local extension known as pull-apart basins, and dikes); (2) a zone of compression at right angles to the zone of extension (within the zone of compression folds can be formed); and (3) a zone of strike-slip faulting that is diagonal to the directions of maximum tensional- and compressional stresses (Figure 28). Within the territory affected by a single strike-slip couple, one gets only those consequences listed; nothing else takes place. If anything else has been done, some other mechanism needs to be sought.

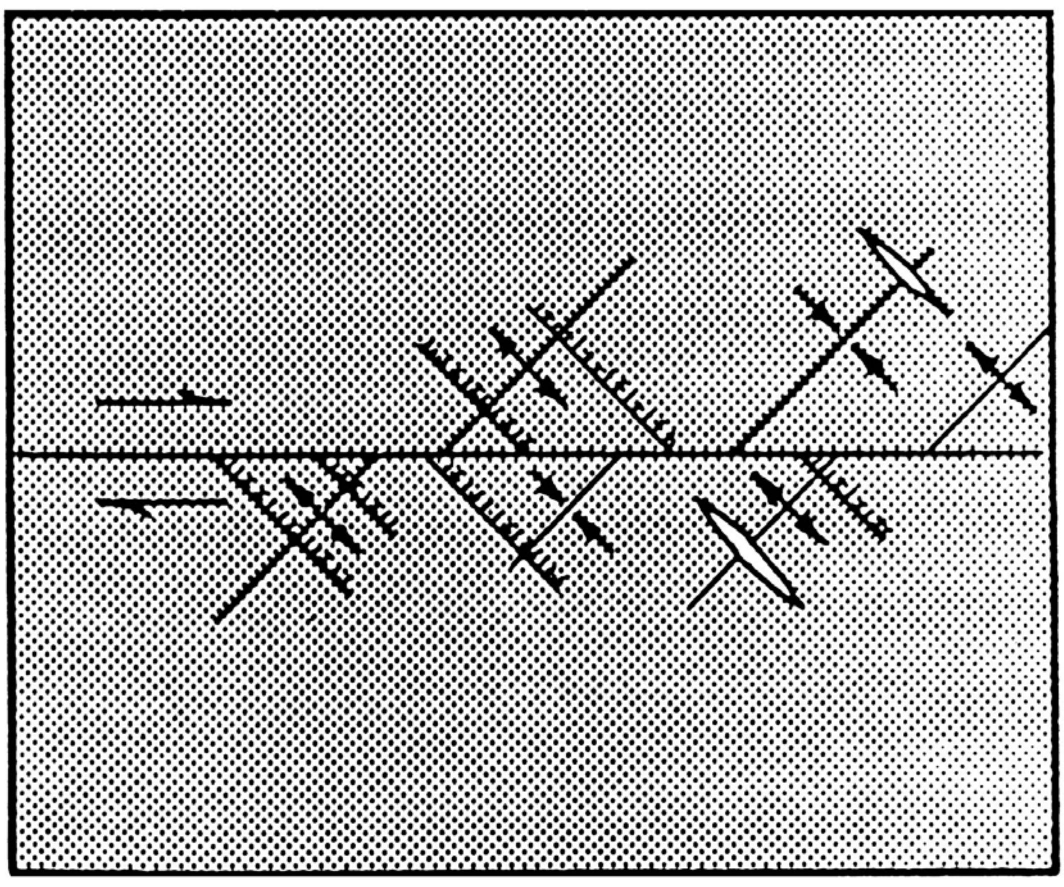


Figure 28. Schematic sketch map of relationships where a right-lateral strike-slip couple has been applied. Vertical right-lateral strike-slip fault crusses center of sketch. Fold axes trend NE-SW; at right angless to the folds are normal faults and open fractures (white areas) trending NW-SE. (J. E. Sanders in G. M. Friedman, J. E. Sanders, and D. C. Kopaska-Merkel, 1992, Box 17.1 fig. 4 (c), p. 633.)

The features of pull-apart basins (Figure 29) have been discussed by Burchfiel and Stewart, 1966; Crowell 1974; Wernike 1985; and Wernike and Burchfiel, 1982). Only Manspeizer (1980) has suggested that part of the Newark basin may be a pull-apart feature.

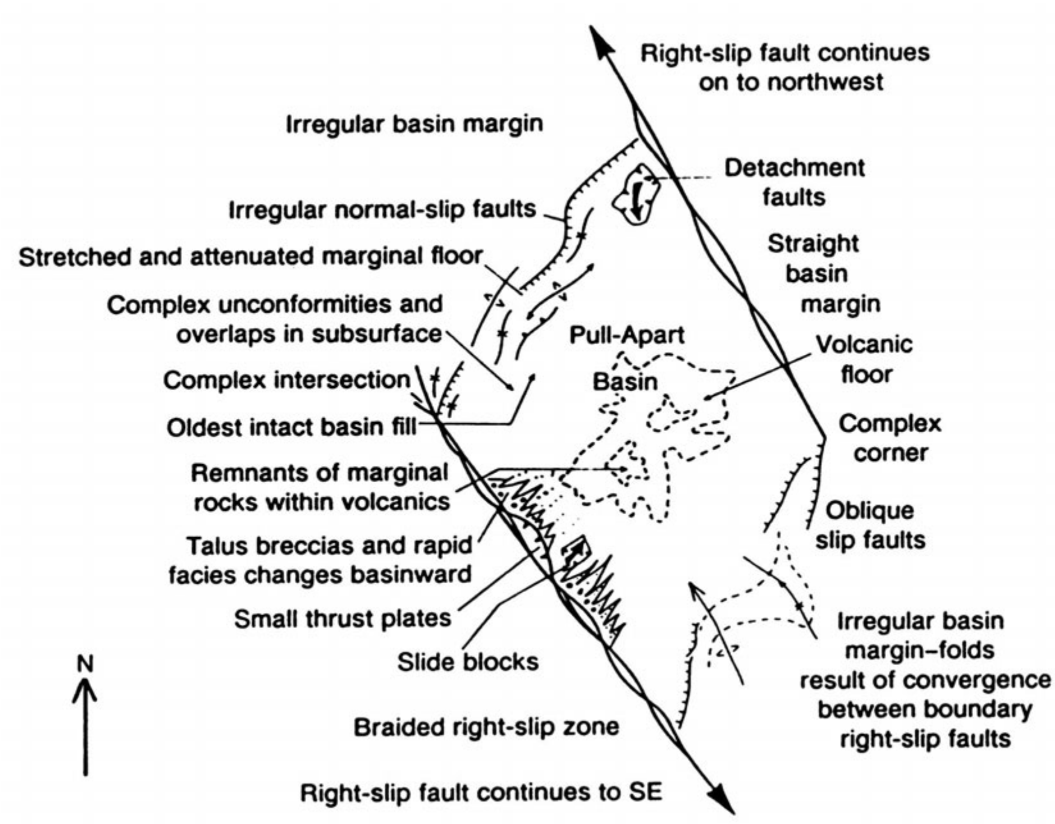


Figure 29. Pull-apart basin seen on schematic tectonic map. (J. C. Crowell, 1974.)

As a prelude to our evaluation of the validity of applying these modern tectonic ideas to the Newark basin, we list and comment on what we regard as some self-evident conclusions about the Newark strata.

Some Important, Self-evident Conclusions (with comments) about the Newark Strata

In this section, we present a numbered list as follows:

1. The Newark strata were deposited on the subsiding block of a basin bounded on the northwest by the Ramapo Fault. The basin-forming movement began late in the Triassic Period roughly 200 Ma.
   This fault movement established a new geologic setting, where previously the Appalchian Mountain chain, which had undergone its climactic deformation early in the Permian Period (about 270 Ma),

had been experiencing uplift and erosion, with the sediments being exported to unknown destinations.

a. The basin-marginal fault(s) coincide with pre-existing zones of weakness, some of which had been active since Proterozoic time (Ratcliffe, 1971).

b. During deposition, this fault was active repeatedly. This repeated activity is indicated by the vertical distribution of basin-marginal rudites throughout all sedimentary formations.

2. Within the Newark basin, drainage was internal. That is, rivers flowed into the lowland and the water either soaked into the sediments or formed lakes. The level of these lakes fluctuated in response to climate cycles having periods ranging from 20,000 to 400,000 years (van Houten, 1962, 1964; Olsen, 1980c, 1984, 1986).

3. The setting in which the Newark strata accumulated persisted for perhaps 30 Ma. At the beginning of the Jurassic Period, a new factor appeared--mafic magma (derived from either the basaltic layer in the continental crust or from the upper mantle). During at least three episodes, this deep mafic magma came to the Earth's surface and was spread out in great lava lakes. The following conclusions are valid with respect to this deep source of magma.

    a. Presumably, the magma was tapped by deep fractures. How deep? This is not known, but it can be hedged in by the following considerations. The continental crust in a newly elevated mountain chain is thick (that is why the chain is elevated). After long-continued erosion, the chain loses its relief--the thickened crust loses thickness by being eroded at the top (Manspeizer, Puffer, and Cousminer, 1978, Figure 7, p. 914, Episode I). After the erosion, the typical thickness might prevail, say between 35 and 40 km.

b. A problem exists between reconciling this indication of fractures capable of tapping a deep magma source and the modern notions about basins forming by lithosphere stretching (as mentioned by Dewey and Bird, 1970, and many others later on). According to this scheme, extension of the lithosphere causes brittle fracture in the upper part of the upper part of the crust, and the faults curve around to become horizontal in the lower, ductile zone. (See Figure 24.)

According to Manspeizer (1980, p. 338-341), the magma did not come up via the basin-marginal faults. In E Pennsylvania, however, in the Cornwall iron district, large mafic plutons are present along the basin-marginal fault (Figure 30).

c. The numerous dikes present in- and near the Newark-type basins may not have been related to the conduits that supplied the lava flows and Palisades intrusive sheet. According to JES, in central CT, many dikes occupy faults that offset the folded sheets of extrusive igneous rock (Sanders, 1963). Sutter and Smith (1979) also emphasized that the basin-central dikes were intruded after the strata had been tilted. They inferred that other conduits, locations not known, fed the lava flows which are interbedded with the sedimentary strata.

4. The entire stratigraphic column, including the interbedded volcanic sheets, accumulated with but minor deviations from horizontality (an example of an exception is the variation in thickness of the sedimentary strata interbedded with the Preakness Formation, discussed by J. V. Lewis, 1907a, 1908a). At some point, deposition stopped,

and all the strata were deformed. JES finds no field evidence to support the concept that the strata became progressively tilted during deposition, as characterizes rift basins. (See Figure 26.)

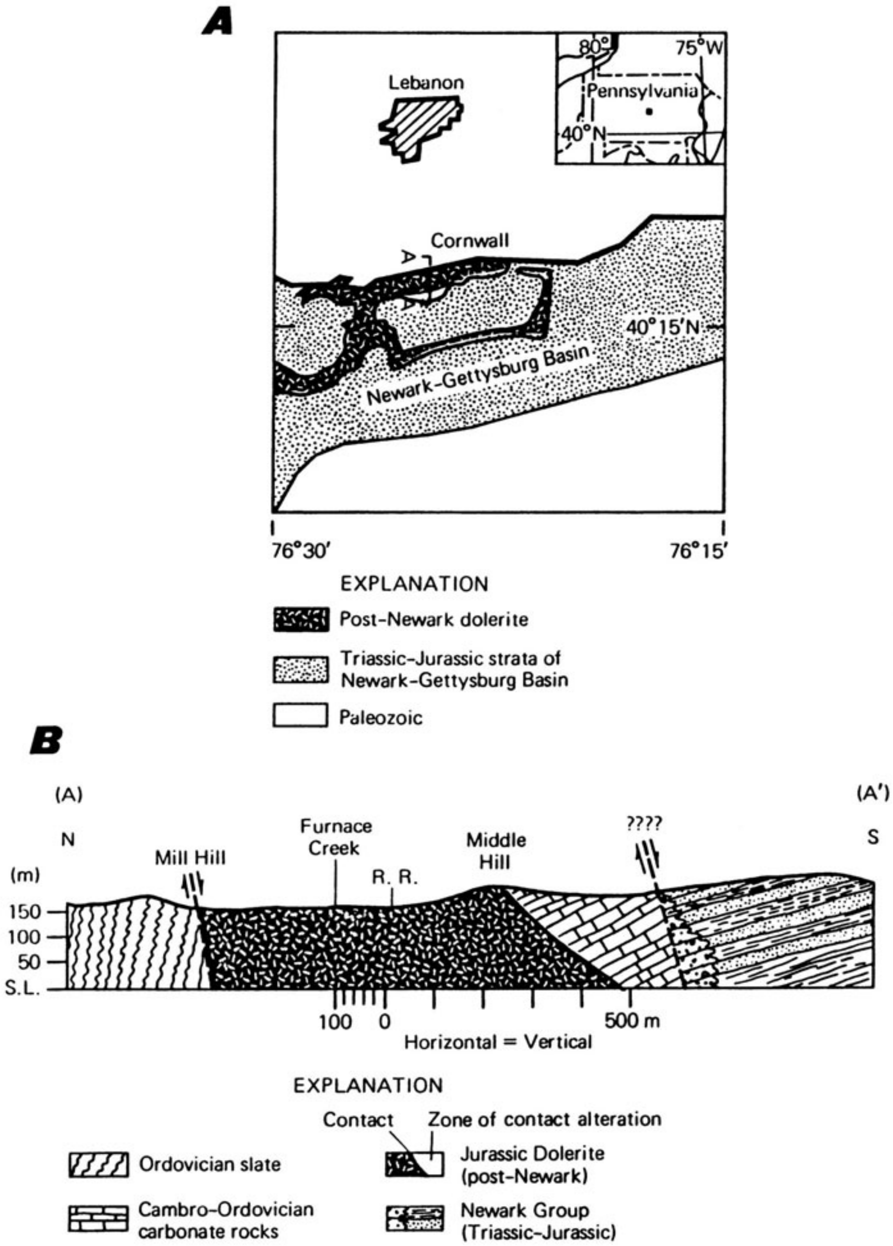


Figure 30. Geologic relationships at Cornwall, Pennsylvania, where a large body of mafic rock has been intruded along Newark-Gettysburg basin-marginal fault (beneath label Mill Hill).

(A) Generalized geologic map; inset shows location in southeastern Pennsylvania.

(B) Profile and geologic section along line AA' showing Jurassic dolerite in fault contact with Ordovician slate at Mill Hill and in intrusive contact with Cambro-Ordovician carbonate rocks at Middle Hill. (J. E. Sanders, 1981, fig. 9.14, p. 236.)

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

Our fundamental reasons for doubting that the Newark basin is a rift basin is the field evidence in support of the view that during the episode of sedimentation, subsidence took place in such a way that the strata were deposited horizontally. In particular, the parallel relationships among the extrusive sheets does not support the concept that significant differential tilting toward the basin-marginal fault took place while strata accumulated.

However, we readily admit that one's explanation of post-Newark folds and -faults basically depends on how one interprets the orientation of the Newark strata. At one end of the ideological spectrum are those who insist that the Newark strata assumed their present attitudes as a result of the operations of the same geologic machinery that caused the Newark basins to form, to subside, and to accumulate sediments. At the other end of this spectrum are those few (including the two of us) who have applied the tried-but-true Stenoan principle "that the strata were essentially horizontal when deposited" and that the modern-day lack of horizontality requires a postdepositional compressive tectonic explanation.

The ultimate in horizontal reference planes is the top of an ancient lava flow; it serves as a kind of gigantic level bubble. Three complexes of ancient lava flows and interstratifed sedimentary strata are present in the Newark basin of northern New Jersey (the tilted, eroded edges of which now form the three Watchung Mountains). As described above, field relationships adequately demonstrate the parallelism of these three sheets of extrusive igneous rocks. The attitudes of these extrusive sheets and their associated sedimentary strata define at least two sets of folds. The vertical axial surfaces of some of these folds are parallel to the basin-marginal faults (=longitudinal folds) and those of others are normal to the basin-marginal faults (=transverse folds). These folds have been offset by several sets of faults (whose existence has been universally acknowledged since the pioneering 19th-century work on them by W. M. Davis [1888a, 1898] in central Connecticut). Lateral offsets of the vertical axial surfaces of some of the transverse folds demonstrate that, along some of the faults that are demonstrably younger than the transverse folds, substantial components of strike-slip offset exist (Sanders, 1962a).

Our efforts in convincing the geological world of Sanders' (minority of one) contentions that the Newark strata have been folded have been gaining favor very slowly (after all, now it's a minority of two - a massive 100% increase!). As expressed above, we argue that four primary surfaces in the Newark basin have been folded and faulted after sedimentation of the basin ceased. These primary, originally horizontal features include bedding, the tops of the Watchung basalt sheets, the basal unconformity at the base of the Newark Supergroup, and the central part of the Palisades sheet. In the post Bird and Dewey (1970) era, most tectonic models attempt to explain Newarkian folds and faults in the context of sea-floor spreading extensional tectonics.

Both longitudinal- and transverse folds have been explained this way in the past except for Sanders' early 1960's publications which stressed the importance of strike-slip faults and related folds. Instead, elaborate manipulations have been proposed to avoid the dreaded "C" word, compression.

A major implication of our interpretation is that the marginal faults were steep, so that they relatively downthrown block could move without significantly rotating. If that is true, then all the modern dips have resulted from post-depositional tectonic activity that differed notably from the tectonic activity which caused the basin to form and its floor to subside relative to the marginal elevated block.

An Alternative Plate-tectonic View of the Newark Basin

Our alternative view of the plate-tectonic history of the Newark basin is that it formed not by massive regional extension, as characterizes rift basins, but rather by differential vertical movement. We visualize the Newark basin as being a small part of a true graben having steep marginal faults. In such an arrangement, the basin itself would be analogous to the dropped keystone block of an arch, known as a crestal-collapse graben.

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

Another point, which we reiterate again, is that we infer that the tectonic setting that ended the life span of the Newark basin differed significantly from that which caused the basin to form and to fill with sediments. We think that the postdepositional history is related to rapid, short-lived plate motions. We first review the possibilities for deformation by application of plate-related strike-slip couples, and then take up the Jurassic continental history of North America.

Structures Formed by Application of Large Strike-slip Couple. One of the fundamental tectonic premises of plate tectonics holds that horizontal plate motion is accompanied by deformation resulting from the application of strike-slip couples. In a previous section, we explained what this means in terms of three zones of compression, of tension, and of strike-slip displacement. We interpret the postdepositional deformation of the Newark in terms of the short-lived- and successive application of three such couples (Sanders, 1971, 1974b). The largest of these is inferred to have been a right-lateral couple with the main slip zone concentrated along 40° north latitude, and to have caused the regional change of strike of the entire Appalachians in southeastern Pennsylvania. This is what S. W. Carey (1953) termed an orocline. The Newark strata have been deformed just as much as the Appalachian. In short, the Newark structures follow the Appalachian structures; they did so before this oroclinal bending and maintain this coincidence after the bending. Therefore, the statement that the Newark faults followed pre-existing Appalachian faults is interesting, but is irrelevant with respect to the subject of the age- and extent of the postdepositional deformation of the Newark.

Mid-Jurassic Plate Re-arrangement. In order to provide a mechanism for the switchover in tectonic style that resulted in the compresssional deformation of the Newark Basin, we need to look westward toward our Cordilleran neighbors. In the Cordilleran belt of the western United States, studies indicate that between Late Triassic and Late-Jurassic time, significant Mesozoic tectonic pulsations took place (Figure 31). These interactions started with a Late Triassic strike-slip faulting "truncation" event, evolved into a mid-Jurassic arc-arc subduction event (the Nevadan Orogeny), and were followed by post-Nevadan Andean subduction that ultimately resulted in the emplacement of the Sierra Nevada Batholith (Schweickert and Cowen, 1975; Schweickert, 1981; Schweickert and Snyder, 1981; Schweickert, Bogen, Girty, Hanson, and Merguerian, 1984; and Schweickert, Merguerian, and Bogen, 1988).

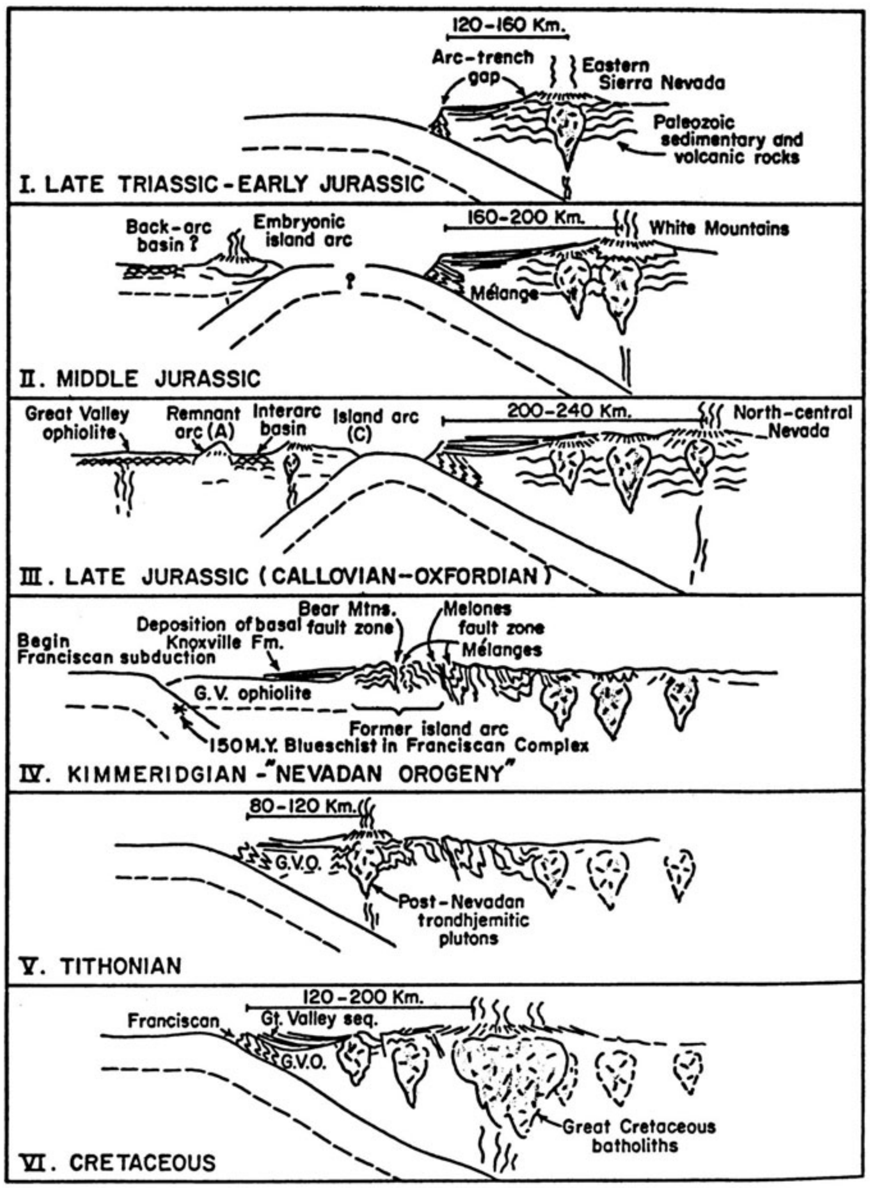


Figure 31. Hypothetical schematic sections showing the postulated tectonic evolution of the Sierra Nevada range during Mesozoic time. (R. A. Schweickert and D. Cowen, 1975, fig. 3, p. 1334.)

Determination of apparent polar-wander (APW) paths for plates is the result of careful paleomagnetic analysis of temporally constrained iron-bearing sediments and mafic igneous rocks from a given region. Researchers (paleomagicians to some) are able to plot as points on an x-y graph (with x and y representing paleolatitude and paleolongitude) the time sequence distribution of paleomagnetic poles. Such poles correspond to the location of the Earth's spin axis as observed from the lithospheric plate under examination. As such, the connection of dated poles of rotation results in (1) gently curved segments (tracks) which indicate linear plate motions, linked by (2) sharply curved segments (cusps) that signify abrupt changes in lithospheric plate motion (translation as well as rotation).

According to Irving and Irving (1982) and Gordon, Cox, and O'Hare (1984), Jurassic North American plate motion was constant but rapid at roughly 7 cm/yr. Mid- to late Triassic motion was even faster. More importantly, apparent-polar-wander paths calculated for the Mesozoic (Figure 32) show two major cusps at 170 Ma and 200 Ma, respectively (mid- to late-Jurassic). These indicate a marked change in plate motions. We suspect these cusps are signals produced by dramatic Mesozoic Cordilleran lithospheric plate interactions. Clearly, the post-Sonoman pre-Late Triassic strike-slip truncation event, Nevadan arc-arc collisional orogeny, and post-Nevadan "Andean" subduction resulted in major Cordilleran plate reconfigurations and mantle-flow reorganization. The age of the 170 Ma cusp is important as it would correspond to a period of time after the Newark basin-filling strata had been deposited. We therefore reach deep into our bag of tricks here to suggest that what was happening way out west affected what we see preserved here on the east! Thus, we would suggest that deformation of the Newark Basin resulted from the combined effects of east-coast mid-Atlantic ridge-push variations (prompted by changes in Atlantic sea-floor spreading rates?) and compressional lithosperic strain transmissions from out west which together resulted in changeovers to compressional tectonics by around 170 Ma, between the terminal-stage Appalachian compression and the post-rift unconformity spreading. The abrupt polar-wander-path changes (cusps) would support these major shifts in plate reorganization. Deformation during activation of the Newark basin margins by strike-slip couples could have forced the deformation of the Newark strata. Undoubtedly, this changeover stage is governed by factors far deeper than the two of us (mantle-flow perturbations and readjustments?) can fathom but we keep our arms waving just the same.

The Atlantic Cycle Begins. After all these strike-slip couples had done their things and had become inactive, perhaps by the end of the Jurassic Period [dated only by "guessing"; but Schlisse (1995) mentions an angular unconformity within the Jurassic in subsurface of Canada offshore] then the new tectonic regime that characterizes a passive continental margin became established.

We regard the Newark episode as being a product of the great plate-tectonic switchover from the setting that culminated in the Appalachian deformation to the setting that has characterized the opening- and spreading of the Atlantic Ocean. In our view, the Newark belongs to neither the Appalachian nor the Atlantic cycles, but is a distinctive product of a short-lived plate-tectonic changover regime that intervened between these two longer-lived tectonic cycles.

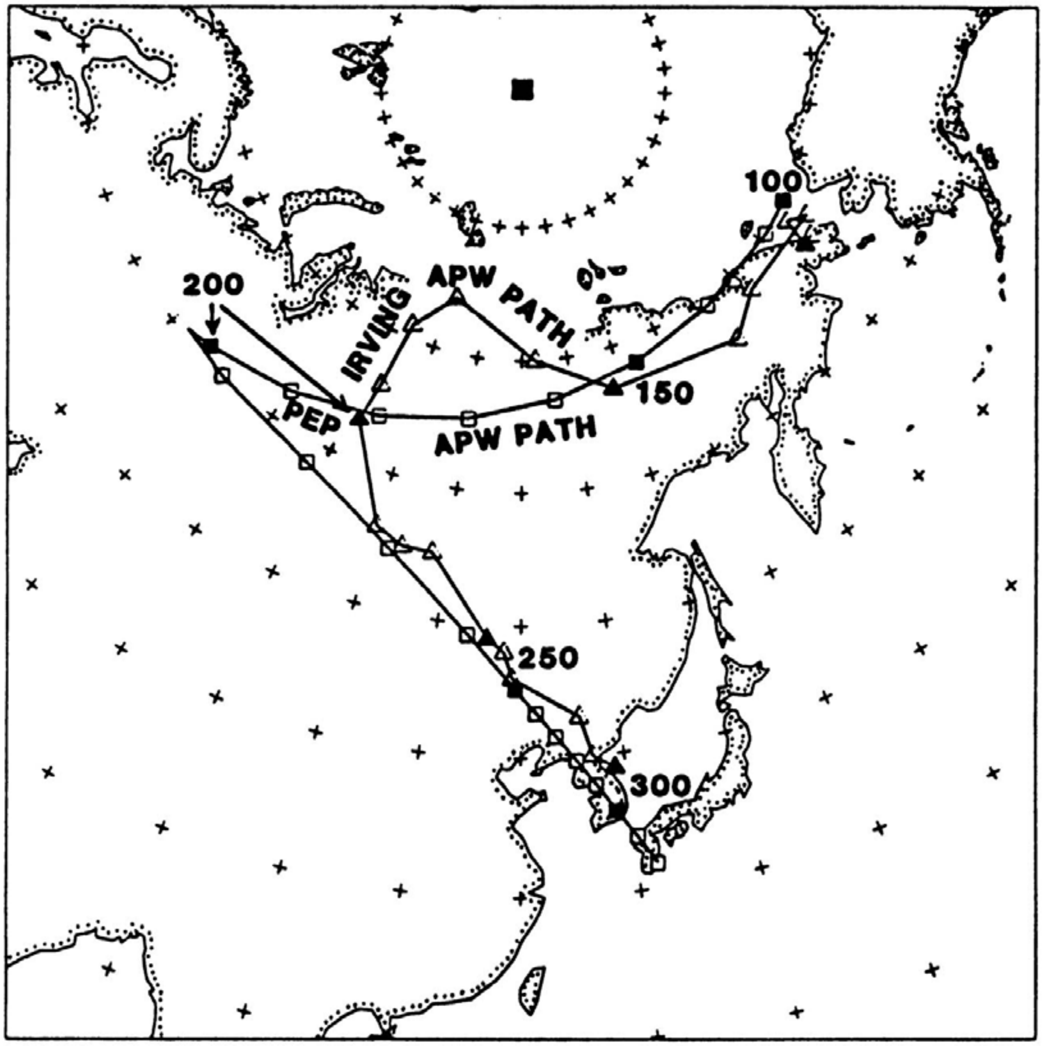


Figure 32. Two conflicting apparent-polar-wander (APW) paths for North America shown at 10 Ma intervals based 1) on the data of Irving and Irving (1982) which shows a cusp at 170 Ma (open triangles) and 2) the data of Gordon, Cox, and O' Hare (1984) which indicates a best-fit Jurassic cusp at 200 Ma (open squares). Stereographic projection. (R. G. Gordon; A. Cox; and S. O' Hare, 1984, fig. 15, p. 524.)

LAYER VI: COASTAL PLAIN STRATA

Not much needs to be mentioned here about the coastal-plain strata other than that they unconformably overlap the tilted, and eroded Newark strata. As mentioned, the coastal-plain strata are the products of the subsidence of a passive continental margin. This setting, which began in the Cretaceous, about 130 million years ago, compares with that established in the Cambrian Period (about 570 million years ago) and which lasted until late in the Ordovician Period (about 420 million years ago, for a duration of about 150 million years). If exact parallelism prevails, then we can expect that in about another 20 million years, the eastern seaboard will be the site of something like the great Taconic overthrust. Stay tuned for further developments.

GLACIAL DEPOSITS

Layer VII: Glacial Deposits and Features

We will not be seeing much in the way of glacial deposits other than erratic boulders eroded out of the till. Kindly refer to our descriptions of the local glacial geology in former guidebooks (Manhattan and the Bronx and Long Island Trips).

DRAINAGE HISTORY

Two points of interest arise in connection with drainage history: (1) the possibility that the Hudson River flowed through the notches in the Watchung ridges, and (2) the proglacial lakes that occupied the lowland enclosed between the Preakness Formation and the Ramapo Range. The first involves the coastal-plain strata; the second, the retreat of the latest Wisconsinan glacier.

The idea that the Hudson River formerly flowed through the notches in the Watchung ridges was proposed by Douglas Johnson (1931). (See Figure 6.) The concept of superposition from the coastal-plain strata was part of Johnson's concept, but he dated this superposition as being from the Cretaceous strata. As is explained by Sanders (1974a), Johnson's concept of superposition might be valid, but if it happened at all, it probably took place during the Pliocene episode of great regional uplift and would have been from the Miocene strata. The condition shown in Figure 6 could have existed during the Pliocene Epoch. (Drawn by E. Raisz for D. W. Johnson, 1931.)

The retreat of the latest Wisconsinan glacier in a north-eastward direction from its terminal moraine (See Figure 3.) generated a large quantity of water. In the lowland enclosed by the Preakness Formation on the south and east, by the Ramapo Range on the west, and by the glacier itself on the north (Figure 33), Lake Passaic formed.

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

OBJECTIVES

1) To study the minerals-, structure, and contact relationships of the Palisades Intrusive Sheet and the Lockatong Formation it has intruded.

2) To learn to distinguish an intrusive sheet from sheet of extrusive igneous rock solidified from an ancient lava flow.

3) To examine the evidence indicating that the paleoflow direction of the Palisades magma was from SW to NE and not from NW to SE.

4) To evaluate the evidence bearing on the state of lithification (or lack of it!) of the sandstones in the Lockatong Formation at the time the Palisades sheet was intruded and from this evidence to estimate the depth of intrusion.

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

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

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

8) To study the evidence for post-depositional faults.

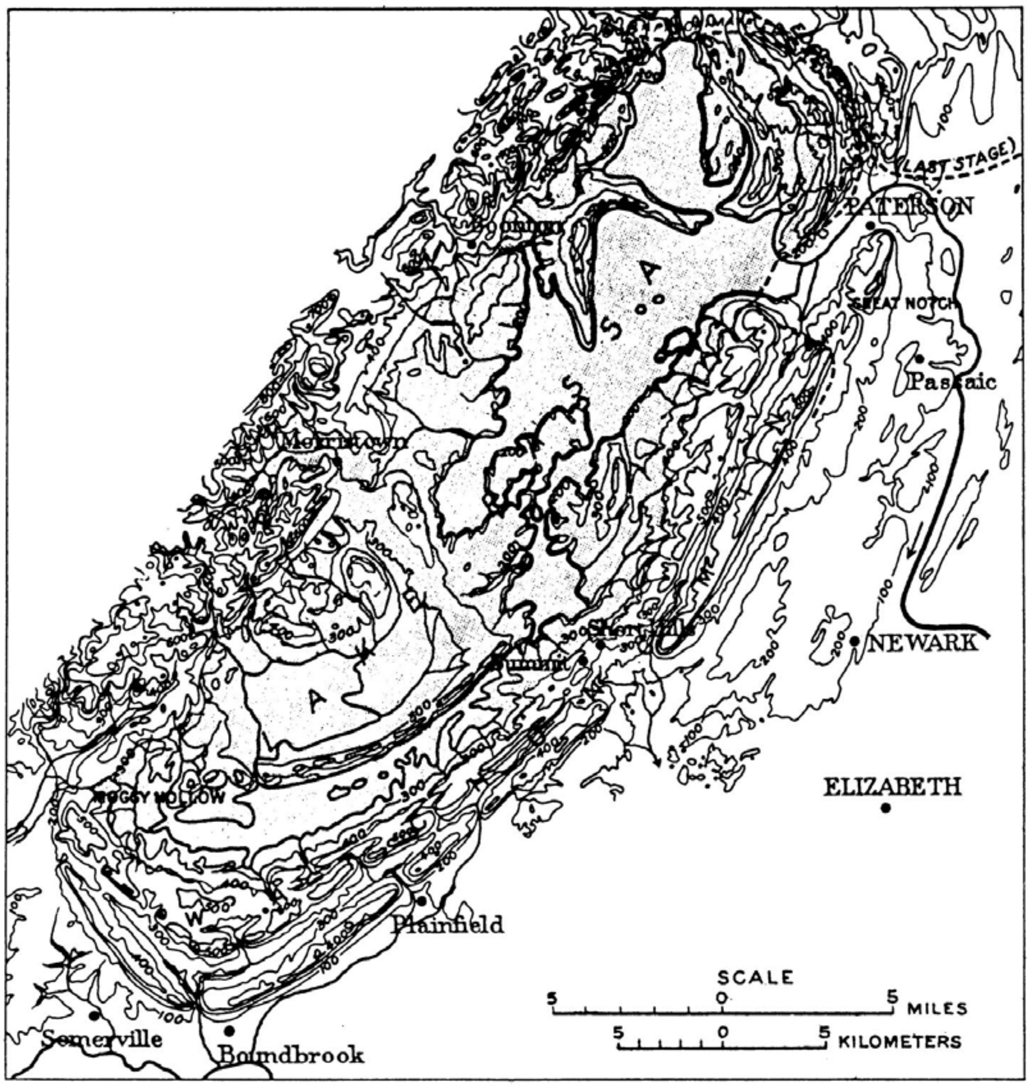


Figure 33. Glacial Lake Passaic (shaded area). (H. B. Kümmel, 1933, fig. 16, p. 71.)

LIST OF LOCALITIES TO BE VISITED

(Stops 1 through 7, in the Newark Basin are shown on the road map, Figure 34).

Figure 34. Road map showing locations of trip stops (numbered). Base from Mobil Travel Map of Greater New York. Scale given by grid squares that are approximately 3.6 miles on a side. True North is at the top of the map.

Stop 1 - Palisades Intrusive Sheet, Olivine Zone, and Lockatong Formation, Palisades Interstate Park.
Stop 2 - Pillowed basalt of Orange Mountain Formation ("First Watchung basalt").
Stop 3 - LUNCH; Lower contact of the Orange Mountain Formation ("First Watchung Basalt") and underlying sedimentary strata of the Passaic Formation (lower part of the Brunswick Formation of pre-Olsen terminology).
Stop 4 - The Great Falls of Paterson (Passaic Falls on Passaic River); Orange Mountain and Passaic formations; evidence for faults.
Stop 5 - Upper, glaciated contact of the Orange Mountain Formation ("First Watchung basalt") at Garrett Mountain Preserve; Garrett Mountain fault block.
Stop 6 - Upper- and lower contacts of the Hook Mountain Formation ("Third Watchung basalt"); basin-marginal rudites of underlying Towaco Formation.
Stop 7 - Basin-marginal rudites of the Feltville Formation, sedimentary strata underlying the Preakness Formation ("Second Watchung basalt").

DRIVING DIRECTIONS

(NYAS to the Newark Basin via the George Washington Bridge and Route 80 eventually to Oakland, New Jersey, and return).

Turn L on 5th Ave. and drive south to 59th St. Turn R across 59th St. to Broadway and turn R driving northward on Broadway to 72nd St. Turn L and get on the West Side Highway northbound to the GWB westbound exit near 178th St.

To Stop 1: Move left one lane; continue across the GWB past the toll plaza and get off at the first exit after the ramp to the Palisades Interstate Parkway (LeMoine Ave.-Center Ave. Routes 67 and 9W). Turn R three times past end of exit ramp and travel south on LeMoine Avenue to rest stop at the Plaza Diner on right. Turn L at Main Street (Bergen County Road 12) and after 0.3 miles merge southward onto River Road. Follow River Road for 0.2 miles south to park entrance (Palisades Interstate Park at Fort Lee).

To Stop 2: Retrace steps for 0.2 miles to Bergen County Road 12 (Main Street) travelling west. Turn R (north) onto Schlosser Street past the Plaza Diner and pass over Route 95. Turn R twice to Route 95 to Route 80 West and take the Express Lanes. Continue west on Route 80 for 14.8 miles to Exit 56 (Squirrelwood Road - West Paterson and Paterson, New Jersey) and bear R at fork at end of exit ramp. Make first L onto Glover Avenue and take Glover down to McBride Avenue (traffic light) along the east side of the Passaic River. Turn R on McBride and travel for 0.7 mi. to outcrop on east side of McBride Ave.

To Stop 3: Continue north on McBride Ave for 0.3 mi.; at traffic light, turn right then jog immediately left and enter the second parking area on the left for the Great Falls Hydroelectric Station. The exposures of interest are along the west side of the municipal parking area just north of the hydroelectric station.

To Stop 4: Leave parking area, turn R; at traffic light turn R again and drive over bridge onto Birch St. After 0.2 mi. turn R past former Dairy Queen (now an open lot) and make next R near stadium and park. (If there is a big crowd at a soccer game, we may walk from Stop 3 to Stop 4.)

To Stop 5: On leaving Great Falls parking area, turn L (notice outcrop of pillowed basalt on W side of street, in a stratigraphic position well above the base of the Orange Mountain Formation). Make first L into Birch St. Cross over the bridge and turn R onto McBride Avenue heading south. At Glover Avenue traffic light turn L. After a few blocks, turn R onto Squirrelwood Road and continue straight over the overpass of Route 80. Before Mobil station, turn L into the Mid-Atlantic Plaza and bear L through parking area past Mid-Atlantic Bank building. Continue ahead and turn L at stop sign onto New Street. After 0.3 mi. note the famous New Street quarry on R and continue 0.1 mi. to Dixon Avenue. Turn R onto Dixon and follow uphill for 0.25 mi., then turn R onto Garrett Street. Follow Garrett around to left and then bear right past blocks of pillowed basalt on Mountain Avenue (Condos on right of Obscene age!). After 0.35 mi. turn L into Garrett Mountain Reservation and turn R into park. Follow road (south) past Barbour Pond. At 0.8 mi. from park entrance turn L at stop sign. Follow road for 0.6 mi. past stop sign and park in small lot to left of road across from the tower.

To Stop 6: Continue north on Garrett Mountain loop access road to exit. Turn L onto main road and at 0.8 mi. turn L onto Weasel Drift Road. Follow up over crest of Garrett Mountain and then down to Valley Road (aka Mountain Park Road). At Getty station, turn L onto Valley Road (northbound) and bear L to Route 19, taking 19 to Route 80 (westbound). Follow Route 80 to Exit 53 (NJ Route 23 northbound). Drive north on NJ 23 to intersection with US Route 202. Turn north on US Route 202 until it joins Hamburg Turnpike. At light in Pompton, where US Route 202 veers N, turn R and R again. Turn into parking area immediately SE of the intersection of Routes NJ 23 and US 202.

To Stop 7: Continue northeasterly on US Route 202 for 2.5 mi. and turn R (beyond the Hillside Diner on R) into South Mall Road to cliff exposures in front of you.

Back to NYAS: Continue north on US Route 202 toward NJ Route 208. After 1.7 mi. turn R onto ramp for NJ Route 208 southbound toward NJ Route 4. In roughly 14 miles, take exit for NJ Route 4 (East) to GWB.

DESCRIPTIONS OF INDIVIDUAL LOCALITIES ("STOPS")

STOP 1 - Palisades Intrusive Sheet, Olivine Zone, and Lockatong Formation at Fort Lee in Palisades Interstate Park, New Jersey branch. [UTM Coordinates: 587.58E / 4522.67N, Central Park quadrangle.]

Exposures along the Palisades Interstate Park access road beneath the George Washington Bridge feature the lower contact of the Palisades intrusive sheet above sedimentary rocks of the Lockatong Formation, former lake deposits in the lower part of the Newark Supergroup [Van Houten (1969), Olsen (1980a), and Puffer (1987)]. The Palisades Intrusive Sheet is one of the world's premier examples of a large sheet of mafic intrusive igneous rock.

The tilted- and eroded edge of the mafic rock is expressed in the landscape as the Palisades ridge along the west side of the Hudson River.

The fact that the olivine zone, which lies about 15 m above the basal contact of the sheet, is visible above the roadbed makes us suspect that the base of the Palisades is exposed at the level of the access road and that the most of the exposed Lockatong is essentially in place, although a few xenoliths and screens are present locally. Our investigations indicate that the sedimentary strata have been contact metamorphosed and that many parts of the contact with the Palisades intrusive are discordant. The strata also display evidence of ductile folding, the probable result of mechanical contrasts between the higher-density magmatic fluid and the contact-heated sediments.

The zone containing abundant olivine crystals is present near the park entrance. Because the olivine-rich rock crumbles much more readily than the rock above it and below it, this rock coincides with a recessed area in the cliff face. The name "rotten rock" or "rotten zone" has been applied to the olivine-rich layer. As all former CCNY geology students know, an excellent exposure of the olivine zone is present to the south in Edgewater, New Jersey, in the cut for the old trolley that took the customers (those wanting to be amused) from the former 125th Street-Edgewater ferry terminal up the cliff to the former Palisades Amusement Park.

Another general feature of the igneous rock is its pattern of columnar joints. One of the characteristics of such joints is that they are oriented perpendicular to the surface against which the igneous rock cooled. From features in the sedimentary strata, we are confident that the strata started out horizontal and were afterward tilted to the NW at their present angle of about 12°. As far as the columnar joints go, their existing attitudes could have resulted from cooling against a horizontal surface and later tilting or from intrusion after the strata had acquired their existing dip.

The cooling joints do not continue through the olivine zone. One possible explanation for this relationship is based on the fact that the accumulated solid olivine crystals would not lose any significant volume. By contrast, the continued cooling of the magma would involve loss of volume by thermal contraction and this loss promotes the formation of the columnar joints. The olivine zone wastes away by granular disintegration. As a result, a recessed zone forms in the cliff face and overlying columns are undermined and thus collapse.

For many years, as a result of petrologic research by investigators named Walker (Frederick Walker, 1940; K. R. Walker, 1969), the olivine zone has been interpreted as being a product of crystal settling from the mafic magma that solidified to form the Palisades, but before this magma had cooled. According to this version of the crystal-settling concept, the olivine crystals grew and then sank, as the result of density contrast, into the Palisades magma chamber as far as they could go. Ultimately, they reached a level about 15 m above the basal contact where they could sink no lower because the chilled marginal parts of the igneous body had solidified to the point where the dense olivine crystals could not penetrate. Recently, this version of the crystal-settling concept has been challenged (Husch, 1990). The alternate explanation is based on chemical considerations and comparisons with the cooling behavior of other mafic sheet-like plutons that were emplaced into the Triassic-Jurassic basin-filling strata of the Newark basins in eastern North America. Chemically, the bulk of these mafic rocks falls within the category known as high-titanium (high-Ti) rocks. In plutons composed of high-Ti magmas, the typical pattern during cooling is for pyroxene (not olivine) to crystallize and for the pyroxene crystals to be concentrated in the basal parts (as the olivine in the Walker interpretation). According to Husch (1990, p. 702):

"The olivine zone may represent the late intrusion of an olivine-normative eastern North America (sic) magma that underwent olivine accumulation prior to its emplacement within the Palisades."

From this, one may conclude that Husch does not reject the concept that the olivine crystals settled out of some magma or other; he just thinks that the settling of the olivine crystals took place from a later injection of magma unlike the one from which most of the Palisades crystallized.

We think that Husch has raised an interesting point that bears further investigation. His paper scarcely qualifies as being the last word on this subject; it is full of mays's, appears's, possibly's, might be's, it seems more likely's and similar "weasel words."

So much for hypothesizing. We can't help but remind the reader of Mark Twain's comment about science, namely that commonly one is able to achieve "a wholesale return in speculation from a trifling investment in fact."

Let us now turn our attention to some things we can see at Stop 1. In order to appreciate the fine points of what is upcoming, it is necessary for everyone to be able to distinguish the igneous rock of the intrusive sheet from the sedimentary rocks of the large xenoliths, which the magma broke off from the Lockatong Formation. Where both are dark-colored rocks having aphanitic texture (crystals so small that individuals cannot be seen without a microscope), special care is required. Fresh igneous rock lacks any bedding and typically displays a bluish-gray color; joint faces tend to weather yellowish brown. [JES ascribes this to the oxidation of a paper-thin film of pyrite and not to weathering of the silicate minerals forming the igneous rock. The basis for this conclusion is that in cores of fresh rock drilled in quarries, a typical feature of the joint faces is a paper-thin layer of pyrite rosettes.] By contrast, the aphanitic sedimentary rock is black and displays bedding ranging from thin laminae to interbeds of light gray silt or very fine sand.

Although many small xenoliths can be found along the contact area of the Palisades intrusive sheet in Fort Lee, the bulk of the sedimentary rock here is in situ (in place) and probably not part of a large xenolith that has been detached from its pre-intrusion position. Within the in-situ strata and the larger xenoliths, it is possible to see the cyclic successions (named Van Houten cycles) that are inferred to have been deposited as the ancient lake level fluctuated from no water to deep water and back again to no water (Olsen, 1980b, p. 352):

"...each can be split into three lithologically identified divisions (from the bottom up): 1, a thin (ca 0.5 m) platy to massive gray siltstone representing a fluvial (sic) and mudflat (sic) to lacustrine (transgressive) facies; 2, a microlaminated (sic) to coarsely laminated black to green-gray fine, often calcareous siltstone (0.1 - 1.0 m) formed during maximum lake transgression; and 3, a generally thickly bedded or massive gray (sic) or gray-red siltstone or sandstone (sic) (0.5 - 4.0 m) usually showing a disrupted fabric and current bedding and sometimes bearing reptile footprints and root horizons (regressive facies)." The mean thickness of these detrital cycles varies from 5.2 m in exposures in the Delaware River valley, central New Jersey, to 1.5 m near Fort Lee." (Figure 35).

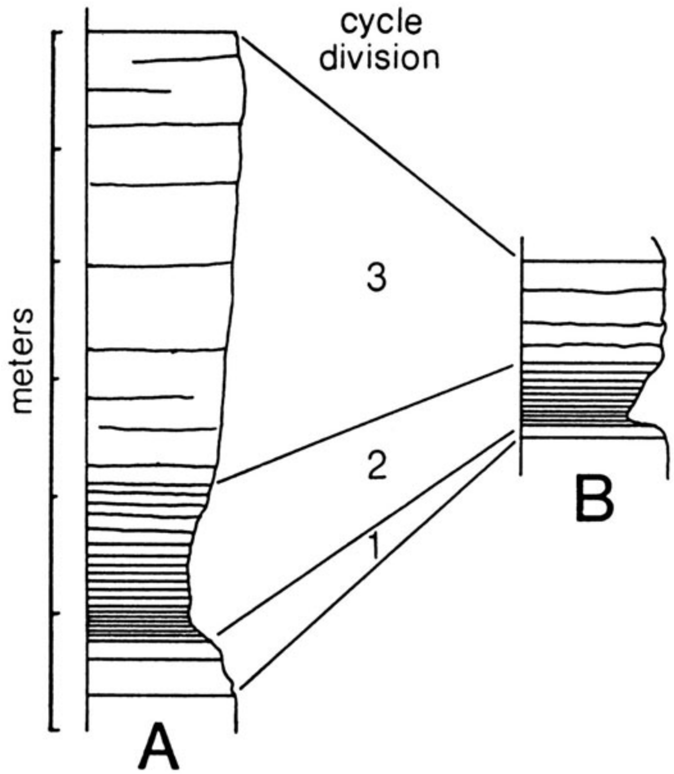


Figure 35. Diagram of generalized Lockatong detrital cycles: A, cycle from center of Newark Basin; B, cycle from northeastern Newark Basin. Cycle division numbers explained in text. (P. E. Olsen 1980c, fig. 1, p. 353.)

"The microlaminated sediments of division 2 are made up of couplets of laminae, one of which is more calcareous than the other (in their unmetamorphosed state) (Fig. 3). Similar sediments are produced in a variety of modern lakes; in most of the studied cases the couplets are the result of seasonal variation in sedimentation and are thus varves." By counting these as varves, Olsen arrived at figures of 20,000 yr per cycle in central New Jersey in contrast with shorter durations (5000 to 10,000 yr) for the cycles at Weehawken.

Olsen supports the interpretation that these cycles were the depositional response to large-scale changes in lake level that were caused by big swings in the Earth's climate. The quantity of water is inferred to have fluctuated between two extremes: (1) plentiful water, resulting in large- and deep lakes, and (2) scanty water, yielding small lakes, possibly even no lakes. Large lakes clearly mean a climate in which rainfall was abundant; small lakes or no lakes imply just the opposite. In terms of the getting-to-be-fashionable language for describing cyclic sediments (proposed by Beerbower, 1964), such changes of level in a lake are assigned to the category of allocyclic (a result of major changes in environment) as contrasted with cyclic deposits that are products of a shifting shoreline or a shifting stream channel and that do not involve major change(s) in the environ-ment (which are named autocyclic).

Immediately north of the George Washington Bridge is a spectacular exposure of the basal contact of the Palisades intrusive sheet. As originally diagrammed by Olson (1980c), and reexamined by your heroes, JES and CM, the Palisades is in discordant contact relationship with a deformed slab of the Lockatong Formation (Figure 36). Above the Lockatong, at the south end of the xenolith, note the chilled aphanitic (very fine) texture in the Palisades at the contact with the metamorphosed sedimentary rock. Microscopic vesicles occur in the chilled-contact basalt suggesting the presence of pore water in the sediments prior to intrusion. What is more, the sandy sediments are chaotic near the contact and have "intruded" upward into the Palisades as "sedimentary apophyses" (See Figure 22.) and clastic dikes. (See Figure 23.)

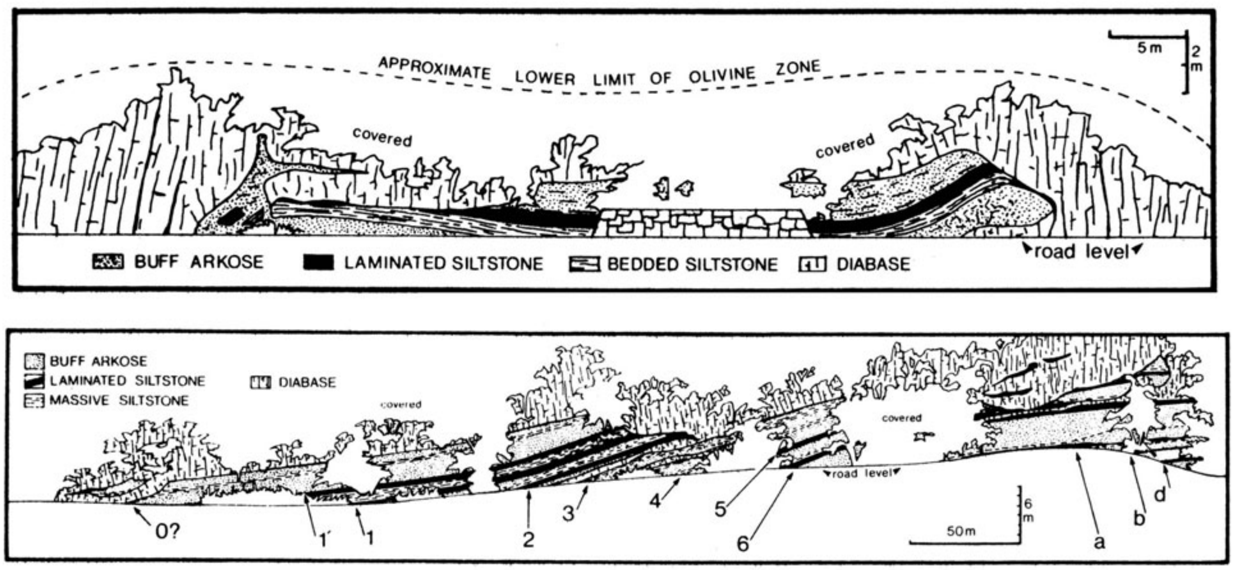


Figure 36. Sketch of exposures on River Road, Palisades Interstate Park south of the traffic circle. Basal contact of sill here is discordant and a large slab of the Lockatong Formation has been bent upward by the Palisades intrusive sheet. (P. E. Olsen, 1980c, fig. 39, p. 387.)

In the same area, a basaltic offshoot, 40 cm thick, intrudes the Lockatong beneath the primary igneous contact. We have found more than a dozen examples of thin (a few cm thick), continuous "dikes" of light-colored, clastic sandy sedimentary material, exhibiting sharp margins, that crosscut the chilled contact rocks and extend upward for more than a meter. Microscopic study of thin sections indicates that these light-colored dikelets [termed "rheomorphic veins" by Walker (1969) and interpreted by him and others as products of partial melting] are, in fact, composed of thermally altered detrital sediments. The microscope discloses altered, contact-metamorphosed remnant clastic textures within these "clastic dikes". Present are diagnostic subrounded feldspars, quartz particles displaying pronounced overgrowths, and other lithic fragments. In the same area within the igneous contact zone, a basaltic offshoot, 40 cm thick, has been found to intrude a xenolith of partly fused Lockatong; chilled basalt has been fractured and intruded by a "clastic dike" 0.5 m thick composed of feldspathic- and quartzose sand. Such relationships may have been produced during cooling of the chilled margin as hot tongues of vapor-charged fluidized, formerly cohesionless sand in the contact zone were "intruded" across the igneous/sediment interface (Merguerian and Sanders 1992, 1994a, 1995a, b).

In addition to the clastic dikes, vesicles, pipe amygdales, and brecciated chilled-margin facies of the Palisades suggest that the mafic magma was intruded at relatively shallow depths (we suspect ~3 to 4 km) where the overburden to which the Lockatong sediments were being subjected had not yet become great enough to cause them to be dewatered and totally lithified. As such, we envision that during intrusion of the mafic magma, at the base of the Palisades intrusive sheet, "wet- and wild" conditions prevailed.

As discussed in detail under the heading Layer V (above), in the Fort Lee area, we have noticed that the intrusive cuts across the bedding at a high angle in a ramp-like fashion toward the north. (See Figure 18.) In addition, immediately beneath the basal contact of the intrusive sheet, the sedimentary strata are broadly arched (See Figure 20.), disposed in tight, chevron folds with vertical, east-west-trending axial surfaces (See Figure 21.), and we have noted asymmetric intrafolial z-folds in the bounding argillites. We have argued (See above.) that the folds could have only formed by differential flow in a SW-NE direction and that, given the discordant ramp-like relationships noted earlier, that here the paleoflow dirction of the Palisades magma must have been from SW to NE. Remembering that a xenolith at the Graniteville quarry of Staten Island was oriented vertically, we wonder whether the feeder for the Palisades intrusive sheet is not centered near Staten Island and that from there, the magma flowed northeastward to Fort Lee. (See Figure 16.) Other investigators have postulated that the magma flowed outward from fractures that trended NE-SW, parallel to the Ramapo fault. If so, in order to reach Fort Lee, the paleoflow direction of the magma would have been from NW to SE. Perhaps the clue to unravelling this issue will be found in the part of the Palisades intrusive sheet southwest of Staten Island, where, if we are correct, paleoflow indicators should indicate the magma moved from NE to SW.

STOP 2 - Pillow basalt of Orange Mountain Formation ("First Watchung Basalt"). East side of McBride Avenue ~0.7 mile NE of intersection of Glover Avenue and McBride Avenue. [UTM Coordinates: 568.1E / 4528.9N, Paterson quadrangle.]

Pillows are ellipsoidal bodies of extrusive igneous rock that cooled rapidly under water. The chilled margins of most pillows are glassy; the texture of the igneous rock within the pillow becomes progressively coarser with distance inward from the margins. In addition to their indications of extrusion under water, pillows can usually be used to determine original top direction with considerable confidence. This results from the fact that where several layers of pillows have accumulated, the bottoms of the upper pillows accommodate themselves to the shapes of the tops of pillows next below. If a single pillow happens to cool more or less in the middle of the gap between two pillows below, then the bottom of the upper pillow will form a kind of protruding part that points downward (Figure 37).

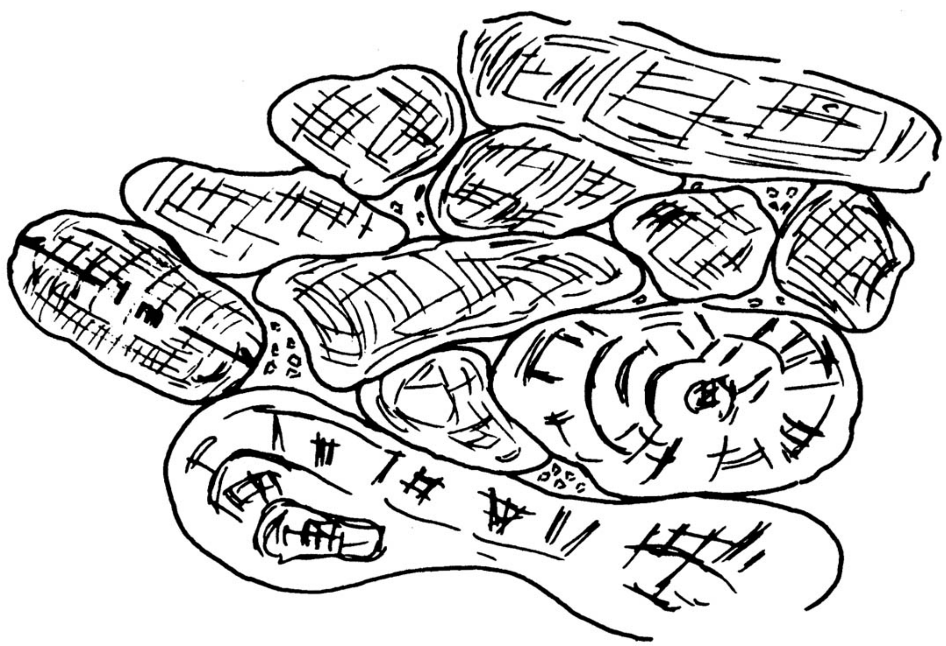


Figure 37. Pillows from Orange Mountain Formation upper New Street Quarry. (Warren Manspeizer, 1980, fig. 14, p. 323)

Geologists exploring the sea floor in research submarines been photographed modern pillows forming where lava oozing out of a fissure reacts with the water in such a way that individual pillows are squeezed out, expand, and then separate. The pillowed part of the Orange Mountain Formation is inferred to have resulted from the extrusion of lava on the bottom of a large lake.

The McBride Avenue exposures are about in the middle of the outcrop belt of the Orange Mountain Formation here. Farther south, however, the pillows are reported from exposures that look to be near the base of the formation (J. V. Lewis, 1908a, 1915b). JES is not familiar with the local stratigraphic details within the Orange Mountian Formation here in Paterson, but sees indications that the Orange Mountain Formation of New Jersey closely resembles the expanded Talcott Formation that JES mapped in southern Connecticut (Sanders, 1962b, 1970; Sanders, Guidotti, and Wilde, 1963). If the Orange Mountain and Talcott are indeed closely similar, then the possibility exists that the Orange Mountain Formation is thicker than many believe and that its pillowed part will be about in the middle.

STOP 3 - Lower contact of the Orange Mountain Formation ("First Watchung Basalt") and underlying sedimentary strata of the Passaic Formation. [UTM Coordinates: 569.00E / 4529.45N, Paterson quadrangle.]

Consult Figure 11 for a general columnar section of the strata of the Newark Supergroup from the top of the Passaic Formation to the Boonton Formation. Figure 38 is a sketch of the exposure in the Municipal Parking Lot.

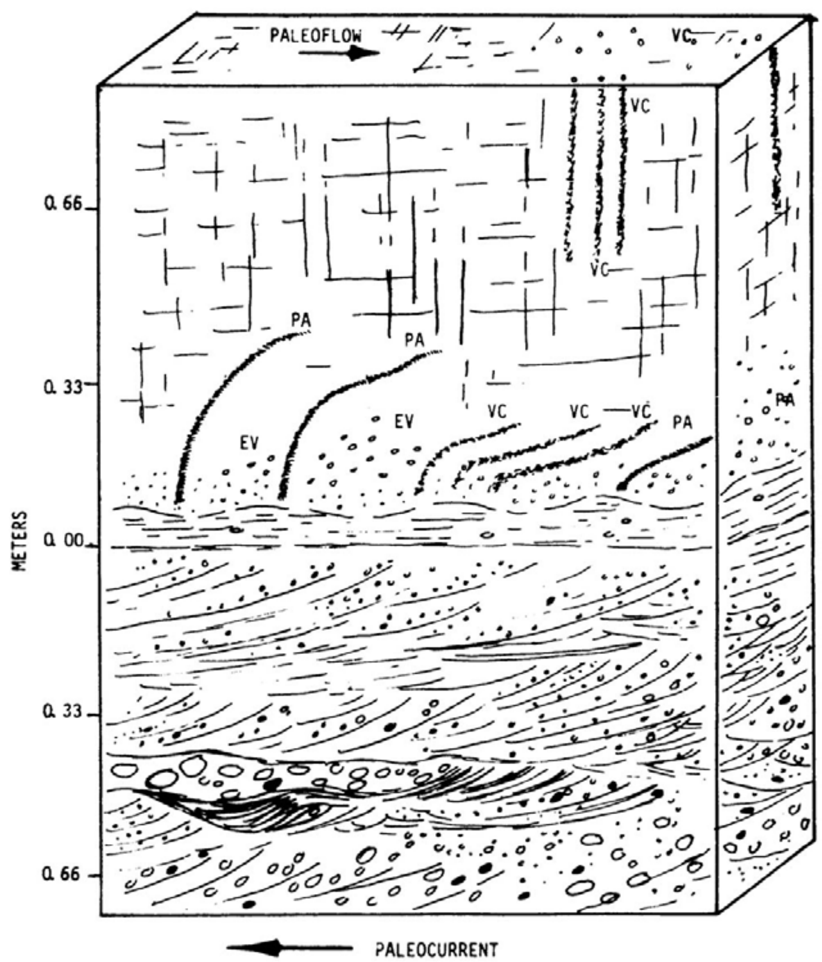


Figure 38. Block diagram of contact between extrusive igneous rock and sandstone, Municipal Parking Lot, Paterson, New Jersey, Stop 3. (Warren Manspeizer, 1980, fig. 6, p. 319.)

In the low cuts one can see the contact between an overlying mafic extrusive igneous rock (Orange Mountain Formation) and a sedimentary rock (top of Passaic Formation). The contact is not a plane surface but displays considerable irregularity. Two possibilities could explain this arrangement: (1) The contact was originally a planar surface (i. e., a bedding-surface) and it was afterward displaced by faults; or (2) shallow stream channels could have been eroded into the top of the Passaic Formation and these channels subsequently filled with lava that solidified to form the Orange Mountain Basalt.

To go about trying to demonstrate which of these possibilities is the correct explanation, one would first try to show the lateral relationships along the contact. If the contact is a faulted bedding surface, then the relationships would be as sketched in Figure 39-A. Evidence of faulting (slickensides, gouge) might be present along the steeply dipping segments of the basalt/sandstone contact. Proof of faulting would consist of finding that these steeply dipping surfaces continue downward as fractures and along them the sedimentary layers below have been displaced.

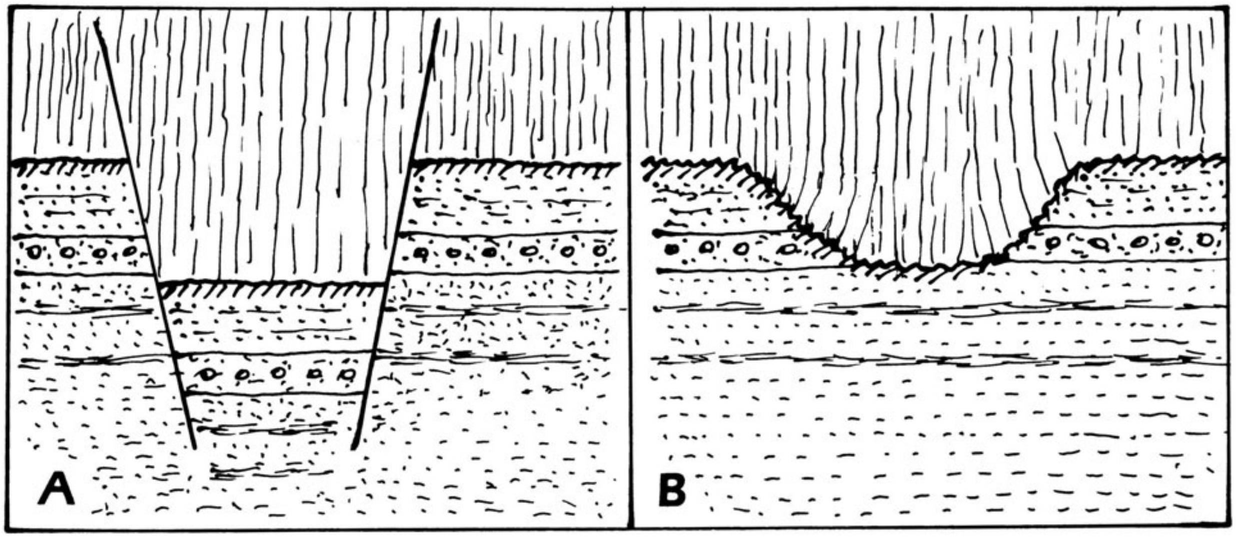


Figure 39. Sketch of irregular contact at base of a lava flow (vertical lines) overlying sandstone (stippled); zone of contact metamorphism at base of lava flow indicated by short closely spaced slanted lines. (JES diagram.)
A - strata offset by fault.
B - lava fills shallow stream valley; strata not offset.

By contrast, if the irregular contact has resulted from lava flowing over the dissected top of the Passaic Formation, then the steep segments of the basalt/sandstone contact would display no evidence of faulting and they would not continue as fractures downward into the sedimentary strata; thus, sedimentary layers below would not be offset (Figure 39-B). A bit of digging and blasting might be required to determine which of these two possibilities is correct.

The direction of in which a sheet of ancient lava flowed can be determined from cylindrical (="pipe") vesicles and -amygdales. Typically these are bent over in the direction toward which the lava flowed. According to Manspeizer (1980, fig. 6, p. 319), pipe amygdales here are bent over toward the NE. (See Figure 38.) This is the opposite to the direction inferred for the paleoslope of the land surface (based on directions of flow of streams that deposited the cross strata). As a result, the lava here onlapped the regional paleoslope.

Passaic Formation. Start by examining the particles and then expand the scale to study the kinds of layers and their relationships (if any) to the particle sizes. The first thing that strikes one is the red color, a function of finely divided hematite that serves as a pigment and, in part, as a cement. The sandstone is coarse and pebbly. Notice the angularity and composition in of the clasts: limestone + quartzite + reworked shale pebbles and cobbles. Weathering out of limestone clasts has left a kind of pitted surface, a kind of "holy stone" (not to be confused with Blarney Stone!), and the 30-cm clast of sandstone within the pebbly sandstone.

From the regional geologic relationships it is known that the Newark basin was filled by nonmarine strata. Accordingly, a strong probability exists that coarse layers would have been deposited by streams. To carry that line of thought one step further, let us compare and contrast the conditions in various kinds of streams. According to Manspeizer (1980, p. 343; description of Stop 2, and A), the regional paleoslope was toward the SW.

Geologic structure. In terms of the three-dimensional arrangements here, see where you would project the contact in a westward direction. Does its projection intersect the river? As you can see by looking across toward the falls, igneous rock of the Orange Mountain Formation forms the narrow gorge and extends all the way to the water level.

STOP 4 - The Great Falls of Paterson, Orange Mountain and Passaic formations. [UTM Coordinates: 568.9E / 4529.5N, hillside exposures E and N of stadium: 569.05E / 4529.75N for contact and 569.15E / 4529.85N for cliff face near dog pound, glacial erratic at 568.95E / 4529.65 N, Paterson quadrangle.]

The waterfall here drops about 75 feet (from the 120-ft contour at the lip to about 45 ft below). The Passaic River, flowing northeastward (more or less parallel to the strike of the tilted strata), pours into a fracture that trends N-S. The water tumbles over the lip on the rock forming the W side of the fracture, and then flows southward along the fracture, then makes a U-turn and continues flowing NE. No gorge has formed downstream, as has been eroded, for example, by the upstream retreat of the lip of Niagara Falls. In its flow along a fracture and absence of a gorge, Great Falls are a miniature version of the mighty Victoria Falls on the Zambezi River in southeastern Africa (Zambia/Zimbabwe).

The quantity of water flowing over Great Falls has been lower than normal lately because of the withdrawals allowed to various upriver communities. They drink this stuff--after treatment, of course.

The view downstream from the footbridge shows that igneous rock extends all the way to the water's edge on the lower level (altitude about 45 ft). Keep this fact in mind as we move northward past the stadium.

Walk back toward the parking lot and proceed down the path toward the river. Stop at the first exposure (on S side of a small knoll beneath the d of the label Stadium; enclosed by the 170-ft contour line). Find the contact at the base of the Orange Mountain Formation (or of one of the extrusive sheets within this formation if not the base) and the underlying pebbly sandstone (top of Passaic Formation or a sedimentary member within the Orange Mountain Formation).

Notice the relationship between the landscape and the contact: a small bench at the top of the sandstone; trees growing where they can send roots into the cliff. The altitude of the contact here is about 100 feet, which is about 50 feet higher than the base of the basalt downstream from the falls. (About 10 years ago, during a class field trip, JES noticed this relationship, but he has not seen it mentioned in other guidebooks and has not examined the geologic map in the US Geological Survey Folio. JES interprets this offset as being the effect of a fault, but the details remain to be determined. In any event, displacement of at least 70 feet is suggested.) CM and JES think that the northward- and upward shift of the basal contact of the extrusive rock is evidence for two other small faults.

Notice the sequence of columnar joints in the extrusive rock and the chilled margin at the base. Right at the base, the joints parallel the basal contast. These give way upward to a zone about 5 m thick that is characterized by large polygonal columns. These two features are not exposed in the gorge downstream of the waterfall. The top of the flow unit is not exposed here, but if it were, what features might be present to enable you to distinguish the sheet as an extrusive as contrasted with an intrusive?

Note the features of the Passaic Formation (if that is what these strata are, and not sedimentary members of the Orange Mountain Formation). Compare with the features seen at Stop 3. In your comparison, include bedding characteristics, sizes of channels, composition of pebbles, and coarseness of particles. Note that the average trend of the channels is S85°W and that the inferred paleoflow of the water in them is from the east! [This is quite in contrast to the accepted view that the Newark Basin filled in with sediment derived from the uplifted highlands (Ramapo Mountains) to the west.]

Note the numbers marked by various methods on the cliff face near the dog pound, an attempt by an unknown geologist(s) to break out individual units. Three channels are especially obvious. The lowest one occurs below unit 5, a second between units 9 and 10, and the third between units 14 and 15. The channels are indicated by sharp contrasts in particle size and by the presence of pebbles in their basal parts. The pebbles are largely (>50%) carbonate with lesser amounts of quartz and recycled red sandstone.

We suggest that the dominantly structureless, uniform, locally laminated sands and interspersed rudites here are the result of flash floods which produced debris flows on the outer fringes of a subaerial fan as contrasted with the upward-fining cross-stratified point-bar successions formed by the migration of meandering streams; in this regard, the absence of shales is especially significant. Thus, we suggest that the sediment blankets are time-stratigraphic deposits similar to their interlayered volcanic conterparts.

On the walk back up the trail, notice the large boulder of Proterozoic gneiss. It is an erratic weathered out of Pleistocene till and must have come from the west, northwest, or north.

STOP 5 - Upper, glaciated contact of the Orange Mountain Formation ("First Watchung basalt") at Garrett Mountain Reservation. [UTM Coordinates of old house: 569.50E / 4577.75N, Paterson quadrangle, altitude: 500 feet.]

From parking lot, follow trail uphill to the building, and then take the trail along the crest of the ridge. Part way up the hill is a large erratic of hornblende-bearing granitic rock from the Proterozoic sequence of the Hudson Highlands. Does the hornblende mean that it came from west of Hudson?

From the crest of the ridge enjoy the splendid view eastward toward Manhattan (atmospheric conditions permitting). Notice the two clusters of skyscrapers: at the Battery and in midtown Manhattan. This is a function of the depth of bedrock. Where the tall buildings have been built, solid bedrock is close to the surface. In between, where no tall buildings have been built, the depth to bedrock becomes several hundred feet.

Along the trail, look for vesicles in the basalt (we are near the top of a flow unit where vesicles are to be expected) and the glacial features. Present here are glacial grooves trending N10°E-S10°W, about parallel to the trend of Garrett Mountain, and a miniature roche moutonnée structure.

The recent floods have been another catastrophe to those living near the junction of the Pompton and Passaic rivers but probably have strengthened the arguments for the US Army Corps of Engineers and sundry politicians who have been advocating the constuction of the flood-diversion tunnel, the proposed route of which is shown by the dots marking core sites in Figure 40. During 1990-91, other cores have been collected at points selected to extend the stratigraphic coverage from the strata penetrated by the line of cores along the proposed route of the flood-diversion tunnel so as to yield cores through the full thickness of the strata filling the Newark basin. These are housed at Lamont-Doherty Earth Observatory of Columbia University and are being studied by Paul Olsen and associates.

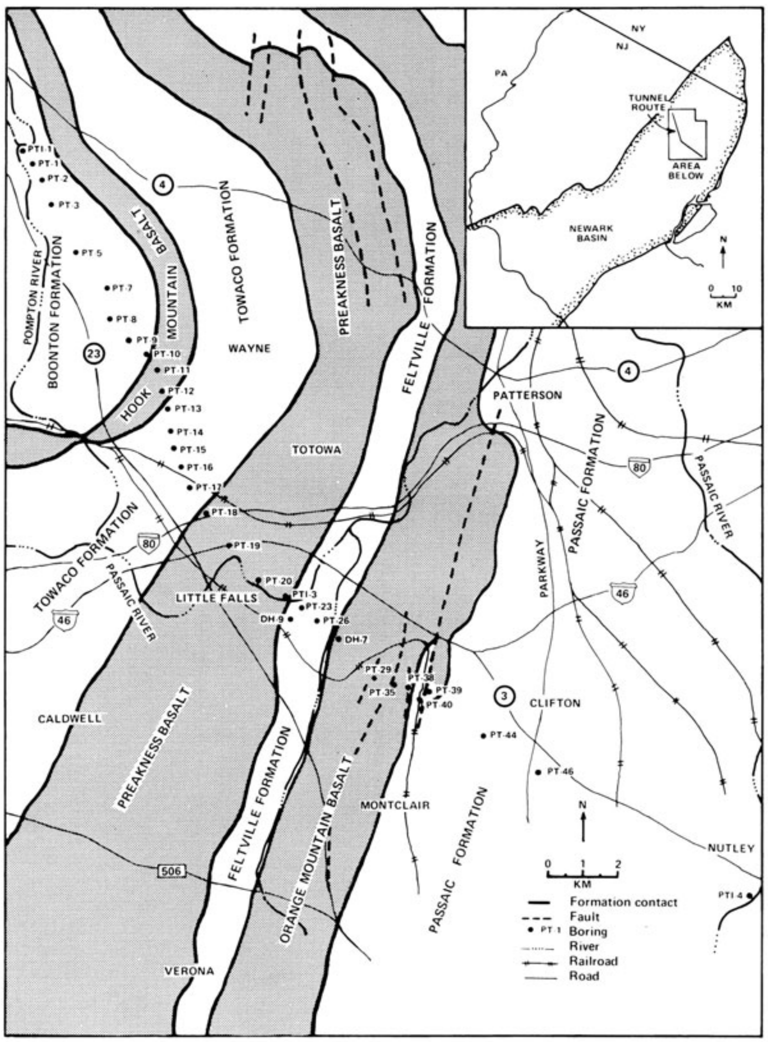


Figure 40. Geologic map in vicinity of proposed flood-diversion tunnel. Dots mark sites of core borings made in 1985 and 1986. (M. S. Fedosh and J. P. Smoot, 1988, fig. 1, p. 20.)

The Garrett Mountain block lies east of a fault that is downthrown on the east. JES suspects that another fault, possibly the one extending northward from the label Orange Mountain Basalt in the lower center of Figure 40, may be upthrown on the east, thus bringing up the Passaic Formation against higher-than-normal parts of the Orange Mountain Formation. JES suspects that this up-on-the east fault extends NE-SW along the eastern side of the First Watchung Mountain. If so, then this fault defines a horst block with the Garret Mountain block. Under this fault hypothesis, the only places where the full thickness of the Orange Mountain Formation would be exposed are located at the northeast- and southwest ends of the Watchung ridges, where the curvature of the strata on the limbs of the transverse Watchung syncline causes the outcrop belts to curve around to the northwest away from this possible fault.

STOP 6 - Upper- and lower contacts of the Hook Mountain Formation ("Third Watchung Basalt"). Near parking lot for shopping center at junction of Paterson-Hamburg Turnpike and Oakland Road, Pompton, in gap cut through Packanack Mountain by Ramapo River where US 202 makes a 90-degree corner at the S end of Pompton Lake. [UTM Coordinates: 560.7E / 4537.8N, Pompton Plains quadrangle.]

The strata here strike NW and dip SW (a result of being on the SW limb of a transverse anticline whose axis strikes NW-SE). The highland about one mile due W of us is underlain by Proterozoic rocks of the Ramapo block; the Ramapo fault, the basin-marginal fault at the NW edge of the Newark basin, lies along the foot of the steep slope. The Ramapo River flows southwestward along the trace of the Ramapo fault.

The top of the Hook Mountain Formation is not visible at Stop 6, but on the basis of the amygdaloidal-vesicular structure of the igneous rock exposed at the edge of the parking lot one can infer that the top is not far away. Refer to Tables 3 for the results of chemical analyses of samples of intrusive igneous rock collected from various parts of the Palisades sheet, and to Table 4, chemical analyses from specimens collected from the extrusive sheets (Orange Mountain and Hook Mountain formations.

The waterfall is made by the Ramapo River flowing over the Hook Mountain Basalt, which as mentioned here strikes NW-SE and dips SW, at a right angle to the Ramapo Fault, which trends NE-SW. Because of this structural arrangement, our traverse from Stop 6 to Stop 7, going parallel to the Ramapo Fault, will be downsection.

The contact at the base of the Hook Mountain Formation is exposed in the cuts along the east side of US Route 202 (if we go there, be careful of the traffic). Notice the sequence of the columnar joints in the basalt and the coarse particles in the basin-marginal rudites of the underlying Towaco Formation.

STOP 7 - Basin-marginal rudites of Feltville Formation [sedimentary strata underlying the Preakness Formation ("Second Watchung basalt")]. Behind Oakland Diner. [UTM Coordinates: 562.2E / 4540.5N, Wanaque quadrangle.]

REST/PIT/REFRESHMENT STOP. After you have rested, pitted, and been refreshed, we will assemble outside to look at the cuts at the edge of the parking lot.

This locality is situated close to the Ramapo fault (buried beneath sediments of Ramapo River at foot of escarpment) near the NW end of Preakness Mountain, the type locality of the Preakness Formation ("Second Watchung Basalt"). The strike of the strata is NW-SE and the dip is to the SW. The sedimentary strata are from near the top of the Feltville Formation. JES uses the general term "basin-marginal rudites" to avoid becoming entangled in the debate about whether these coarse materials were deposited on subaerial fans, sublacustrine fans, or even on lacustrine beaches. The critical information for deciding about the environment of deposition is not exposed here. What can be seen here, however, is an abundance of boulders of Cambro-Ordovician carbonates (mostly dolostones, not metamorphosed, and some limestones), vesicular basalt (presumably derived by eroding the Orange Mountain Formation), and Green Pond Conglomerate (basal unit of Layer IIIE of Table 2); and medium-rare boulders of Proterozoic gneiss (hold the steak sauce, please!). The predominance of pieces from the Paleozoic sedimentary formations indicates that the main body of the Proterozoic rocks forming the Ramapo block in today's landscape had not yet been exposed during the early part of the Jurassic Period when the Feltville Formation was being deposited.

At Oakland, we have ended a traverse downsection that began at the top of the Hook Mountain Basalt. We have cut through the entire Towaco Formation and the Preakness Formation and are in the topmost part of the Feltville Formation. Despite this change in stratigraphic position, the kind of rock (rudite) has remained about the same. Put another way this means that in localities within about a mile or so of the Ramapo fault, nearly all sedimentary formations consist of basin-marginal rudites. The total stratigraphic range of such rudites has not been determined, but it might come close to equaling the entire thickness of the Newark basin-filling strata.

Why do you suppose that all the boulders are cut by fractures? (Are they really what they are cracked up to be?)

ACKNOWLEDGEMENTS

Our interest in the Palisades has been the direct result of conducting, since 1988, the On-The-Rocks field trip program for the New York Academy of Sciences. We thank, together with our On-The-Rocks devotees, the many students of geology from Hofstra University who have visited the area with us and provided useful discussion. We thank Dr. Simon Schaffel for spending two days in the field arguing against our ideas and Dr. Alan I. Benimoff for showing us the Graniteville exposure. Charles Salomon, currently a Hofstra graduate, prepared thin sections and completed a senior research project on the Palisades contact. Hofstra student Jessica Levine assisted in collating reference materials and xerography. Support from the Geology Department of Hofstra University and Duke Geological Laboratory is gratefully acknowledged.

Thanks to Matt Katz, and Marcie Brenner (the true power at the Academy) for facilitating registration and logistics for our field trip series.

TABLES

Table 01 - GEOLOGIC TIME CHART

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

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

PALEOZOIC 245

(Permian)		Pre-Newark erosion surface formed.
	260	**Appalachian orogeny.** (Terminal stage.) Folding, overthrusting, and metamorphism of Rhode Island coal basins; granites intruded.
(Carboniferous)		Faulting, folding, and metamorphism in New York City area. Southeastern New York undergoes continued uplift and erosion.
(Devonian)	365	**Acadian orogeny.** Deep burial of sedimentary strata. Faulting, folding, and metamorphism in New York City area. Peekskill Granite and Acadian granites intruded.
(Silurian)		
	440	**Taconic orogeny.** Intense deformation and metamorphism.
	450	Cortlandt Complex and related rocks intrude Taconian suture zone. (Cameron's Line and St. Nicholas Thrusr Zone). Arc-continent collision. Great overthrusting from ocean toward continent. Taconic deep-water strata thrust above shallow-water strata.
(Ordovician)		Ultramafic rocks (oceanic lithosphere) sliced off and transported structurally above deposits of continental shelf. Shallow-water clastics and carbonates accumulate in west of basin. (= **Sauk Sequence**; protoliths of the Lowerre Quartzite, Inwood
(Cambrian)		Marble, Walloomsac Schist). Transitional slope/rise sequence (Manhattan Schist) and deep-water terrigenous strata (Hartland Formation) form to east. (= **Taconic Sequence**).

PROTEROZOIC

	570	Period of uplift, rifting,and erosion followed by subsidence of margin and development of **Iapetan Passive-Margin Stage I**.
(Z)	600	Rifting with rift sediments, volcanism, and intrusive activity. (Ned Mountain, Pound Ridge, and Yonkers gneiss protoliths).
(Y)	1100	**Grenville orogeny.** Sediments and volcanics deposited, compressive deformation, intrusive activity, and granulite facies metamorphism. (Fordham Gneiss, Hudson Highlands and related rocks).

ARCHEOZOIC

	2600	No record in New York.
	4600	Solar system (including Earth) forms.

Table 02

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

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

LAYER VII - QUATERNARY SEDIMENTS

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

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

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

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

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

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

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

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

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

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

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

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

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

LAYER IV - COAL MEASURES AND RELATED STRATA (Carboniferous)

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

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

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

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

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

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

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

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

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

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

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

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

LAYER IIA [W] - SAUK SEQUENCE

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

Copake Limestone (Stockbridge,
Rochdale Limestone (Inwood Marble)
Halcyon Lake Fm.
Briarcliff Dolostone
Pine Plains Fm.
Stissing Dolostone
Poughquag Quartzite
Lowerre Quartzite
Ned Mtn Fm.

LAYER IIA [E] - TACONIC SEQUENCE

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

(Ꞓ-Oh) Hartland Fm.
(Ꞓ-Om) Manhattan Fm.

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

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

LAYER I - PROTEROZOIC BASEMENT ROCKS

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

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

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

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

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

Table 03 - Chemical analyses of Newark igneous rocks, New Jersey
(J. V. Lewis, 1908a, p. 121-122)
(Palisades Sill, from bottom, lower part, middle, and top)

Element	**IV**	**V**	**VII**	**VIII**	**IX**	**X**
SiO_2	51.88	50.40	49.62	51.14	51.03	49.02
TiO_2	1.35	1.35	1.01	1.13	0.93	0.99
Al_2O_3	14.53	15.60	10.51	12.99	11.92	10.14
Fe_2O_3	1.35	3.65	0.64	1.50	1.52	1.54
FeO	9.14	6.30	12.02	9.14	10.85	10.46
MgO	7.78	6.08	15.98	11.58	12.08	17.25
CaO	9.98	10.41	7.86	10.08	9.22	8.29
Na_2O	2.06	3.57	1.40	1.72	1.50	1.59
K_2O	0.93	0.62	0.67	0.42	0.39	0.40
H_2O	----	----	----	----	----	----
H_2O^+	0.97	1.67	0.49	0.59	0.54	0.59
H_2O^-	0.12	1.02	0.39	0.14	0.17	0.16
MnO	0.10	0.06	0.09	0.16	0.15	0.16
P_2O_5	0.14	0.16	0.16	0.06	0.08	0.11
CO_2	----	----	----	----	----	----
Totals	100.33	99.89	100.71	100.75	100.38	100.70
Sp.Gr.	2.98	2.89	3.118	3.051	3.122	3.152

IV: Basaltic diabase, Weehawken; lower contact in Pennsylvania RR tunnel, R. B. Gage, analyst.
V: Basaltic diabase, New York, Susquehanna and Western railroad tunnel, upper contact at west portal, R. B. Gage, analyst.
VII: Olivine diabase, Weehawken, road to West Shore Ferry; typical coarse diabase, R. B. Gage, analyst.
VIII: Diabase, Englewood Cliffs, below the olivine diabase, R. B. Gage, analyst.
IX: Diabase, Englewood Cliffs, coarse rock above the olivine diabase, R. B. Gage, analyst.
X: Olivine diabase, Englewood Cliffs; typical, coarse. R. B. Gage, analyst.

Table 04 - Chemical analyses of Newark igneous rocks, New Jersey
(J. V. Lewis, 1908a, p. 159, 161)

	(Orange Mountain Formation)						(Hook Mountain Fm.)		
Element	**I**	**IV**	**VI**	**II**	**V**	**III**	**VII**	**VIII**	**IX**
SiO_2	50.19	51.82	51.36	51.09	51.84	51.77	49.68	49.17	49.71
TiO_2	1.13	1.17	----	1.30	1.22	1.13	1.39	1.50	1.53
Al_2O_3	14.65	14.18	16.25	14.23	15.11	14.59	14.02	13.80	13.66
Fe_2O_3	3.41	0.57	2.14	2.56	1.78	3.62	4.97	4.90	5.49
FeO	6.96	9.07	8.24	7.74	8.31	6.90	9.52	10.61	9.51
MgO	7.95	8.39	7.97	7.56	7.27	7.18	5.80	5.04	6.13
CaO	9.33	8.60	10.27	10.35	10.47	7.79	6.50	9.87	5.85
Na_2O	2.64	2.79	1.54	1.92	1.87	3.92	3.49	2.21	4.51
K_2O	0.75	1.26	1.06	0.42	0.34	0.64	1.41	0.54	0.37
H_2O	----	----	----	----	----	----	----	----	----
H_2O^+	2.38	1.40	1.33	1.01	1.33	1.85	1.89	0.73	2.66
H_2O^-	0.66	0.30	----	1.66	0.56	0.46	0.54	1.04	0.48
MnO	0.07	0.13	0.09	0.25	0.09	0.05	0.18	0.07	0.13
P_2O_5	0.18	----	0.21	0.16	0.13	0.18	0.17	0.24	0.10
$Ni0_2$	----	----	0.03	----	----	----	----	----	----
SrO	----	----	----	----	----	----	tr	0.03	----
Totals	100.30	99.85	100.28	100.25	100.32	100.08	99.60	99.75	100.13
Sp.Gr.	2.92	2.95	----	2.936	2.93	2.91	2.949	2.997	2.91

Orange Mountain Formation:
I. Hartshorn's Quarry, nr. Springfield and Short Hills ("lower gray").
(An. No. 121; spec. and thin section 309-L; R.B. Gage, analyst).
IV. Hatfield and Weldon's Quarry, Scotch Plains ("lower gray").
(An. No. 130; spec. and thin section 35-L; R.B. Gage, analyst).
VI. O'Rourke's Quarry, West Orange (large columns near bottom).
(U. S. Geol. Survey Bull. 150, p. 255; L. G. Eakins, analyst).
II. Hartshorn's Quarry, nr. Springfield and Short Hills ("middle black layer").
(An. No. 120; spec. and thin section 308-L; R.B. Gage, analyst).
V. Hatfield and Weldon's Quarry, Scotch Plains ("middle black layer").
(An. No. 131; spec. and thin section 36-L; R. B. Gage, analyst).
III. Hartshorn's Quarry, nr. Springfield and Short Hills ("upper gray layer").
(An. No. 122; spec. and thin section 310-L; R.B. Gage, analyst).

Hook Mountain Formation:
VII. Morris County Crushed Stone Co.'s Quarry, Millington ("lower gray").
(An. No. 123; spec. and thin section 245-L: R.B. Gage, analyst).
VIII. Same locality ("middle black layer")
(An. No. 124; spec. and thin section 246-L; R.B. Gage, analyst).
IX. Same locality ("upper gray layer")
(An. No. 125; spec. and thin section 247-L; R.B. Gage, analyst).

REFERENCES CITED

Abdel-Monem, A. A., and Kulp, J. L., 1968, Paleogeography and the source of sediments of the Triassic basin, New Jersey, by K-Ar dating: Geological Society of America Bulletin, v. 79, p. 1231-1242.

Adams, G. F., 1980, Fault patterns at the Peapack offset of the Ramapo border fault New Jersey Triassic (abstract): Geological Society of America Abstracts With Programs, v. 12, no. 2, p. 21 (only).

Armstrong, R. L.; and Besancon, James, 1970, A Triassic time scale (sic) dilemma; K-Ar dating of Upper Triassic mafic igneous rocks, eastern U. S. A. and Canada and post-Upper Triassic plutons, western Idaho, U. S. A.: Eclogae Geologicae Helvetiae, v. 63, no. 1, p. 15-38.

Bain, G. W., 1957, Triassic age (sic) rift structure in eastern North America: New York Academy of Sciences Transactions, series II, v. 19, p. 489-502.

Barr, D., 1987a, Lithospheric stretching, detached normal faulting and footwall uplift, p. 75-94 in Coward, M. P.; Dewey, J. F.; and Hancock, P. L., eds., Continental extensional tectonics: London, UK, Geological Society of London Special Publications No. 28, 637 p.

Barr, D., 1987b, Structural/stratigraphic models for extensional basins of half-graben type: Journal of Structural Geology, v. 9, p. 491-500.

Barr, D., 1991, Subsidence (sic) and sedimentation in semi-starved half-graben (sic): a model based on North Sea data, p. 17-28 in Roberts, A. M.,; Yielding, Graham; and Freeman, B., eds., The geometry (sic) of normal faults: London, UK, Geological Society of London Special Publication No. 56, xxx p.

Barton, P.; and Wood, R., 1984, Tectonic evolution of the North Sea basin: Crustal stretching and subsidence: Royal Astronomical Society Geophysical Journal, v. 79, p. 987-1022.

Beerbower, J. R., 1964, Cyclothems and cyclic depositional mechanisms in alluvial plain (sic) sedimentation, p. 31-42 in Merriam, D. F., ed., Symposium on cyclic sedimentation: Kansas Geological Survey Bulletin 169, 2 vols. (v. 1, p. 1-380; v. 2, p. 381-636).

Benimoff, A. I., and Sclar, C. B., 1984, Coexisting silicic (sic) and mafic melts resulting from marginal fusion of a xenolith of Lockatong Argillite in the Palisades sill, Graniteville, Staten Island, New York: American Mineralogist, v. 69, nos. 11/12, p. 1005-1014.

Benimoff, A. I., and Sclar, C. B., 1988, The Graniteville quarry, Staten island, NY: An outstanding location for illustrating igneous phenomena: Northeastern Geology, v. 10, p.. 1-10.

Benson, R. N., 1984, Structure contour (sic) map of Pre-Mesozoic basement, landward margin of Baltimore Canyon trough: Delaware Geological Survey Miscellaneous Map Series, No. 2 (scale l:500,000).

Benson, R. N., and Doyle, R. G., 1988, Early Mesozoic rift basins and the development of the United States middle Atlantic continental margin, in Manspeizer, Warren, ed., Triassic-Jurassic rifting, continental breakup and the origin of the Atlantic Ocean and passive margin: Amsterdam, The Netherlands, Elsevier Science Publishers, 998 p. (2 volumes).

Berkey, C. P., 1948, Engineering geology in and around New York, p. 51-66 in Creagh, Agnes, ed., Guidebook of Excursions: Geological Society of America Annual Meeting, 61st, New York City, 135 p.

Bird, J. M., and Dewey, J. R., 1970, Lithosphere-continental margin (sic) tectonics and the evolution of the Appalachian orogen: Geological Society of America Bulletin, v. 81, p. 1031-1059.

Bond, K. R., and Phillips, J. D., 1988, Aeromagnetic imagery with geologic correlations for some early Mesozoic basins of the eastern United States, p. 253-264 in Froelich, A. J.; and Robinson, G. R., Jr., eds., Studies of the Early Mesozoic basins of the eastern United States: United States Geological Survey Bulletin 1776, 423 p.

Bott, M. H. P., 1964, Formation of sedimentary basins by ductile flow of isostatic origin in the upper mantle: Nature, v. 201, p. 1082-1084.

Bott, M. H. P., 1971, Evolution of young continental margins and formation of shelf basins: Tectonophysics, v. 11, p. 319-327. Bott, M. H. P., ed., 1976a, Sedimentary basins of the continental margin and craton: Inter-Union Commission on Geodynamics Symposium, Durham University, England, 05-09 April 1976, Proceedings: Tectonophysics, v. 36, nos. 1-3 (special issue), 314 p.

Bott, M. H. P., 1976b, Mechanisms of basin subsidence--an introductory review, p. 1-4 in Bott, M. H. P., ed., Sedimentary basins of the continental margin and craton: Inter-Union Commission on Geodynamics Symposium, Durham University, England, 05-09 April 1976, Proceedings: Tectonophysics, v. 36, nos. 1-3 (special issue), 314 p.

Bott, M. H. P., 1976c, Formation of sedimentary basins of the graben type by extension of continental lithosphere, p. 77-86 in Bott, M. H. P., ed., Sedimentary basins of the continental margin and craton: Inter-Union Commission on Geodynamics Symposium, Durham University, England, 05-09 April 1976, Proceedings: Tectonophysics, v. 36, nos. 1-3 (special issue), 314 p.

Brock, P. J. C., 1989, Stratigraphy of the northeastern Manhattan Prong, Peach Lake quadrangle, New York-Connecticut, p. 1-27 in Weiss, Dennis, ed., New York State Geological Association Annual Meeting, 61st, Field trip guidebook: Middletown, NY, Orange County Community College, Department of Science and Engineering, 302 p.

Brock, P. J. C., 1993 ms., Geology of parts of the Peach Lake and Brewster quadrangle, southeastern New York and adjacent Connecticut, and basement blocks of the north-central Appalachians: New York, NY, City University of New York Graduate Faculty in Earth and Environmental Sciences, Ph. D. Dissertation, 494 p., 6 plates.

Brotchie, J. F., and Silvester, R., 1969, On crustal flexure: Journal of Geophysical Research Research, v. 74, p. 5240-5252.

Bucher, W. H., and Kerr, P. F., 1948, Excursion to the First Watchung basalt at Paterson, New Jersey, p. 109-116 in Creagh, Agnes, ed., Guidebook of Excursions: Geological Society of America Annual Meeting, 61st, New York City, 135 p.

Burchfiel, B. C., and Stewart, J. H., 1966, "Pull-apart" origin of the central segment of Death Valley, California: Geological Society of America Bulletin, v. 77, p. 439-442.

Burke, Kevin, 1976, Development of graben associated with the initial ruptures of the Atlantic Ocean, p. 93-112 in Bott, M. H. P., ed., Sedimentary basins of the continental margin and craton: Inter-Union Commission on Geodynamics Symposium, Durham University, England, 05-09 April 1976, Proceedings: Tectonophysics, v. 36, nos. 1-3 (special issue), 314 p.

Carey, S. W., 1953, The orocline concept in geotectonics: Royal Society of Tasmania Proceedings, v. 89, p. 255-288.

Carlisle, Donald, 1963, Pillow breccias and their aquagene tuffs, Quadra Island, British Columbia: Journal of Geology, v. 71, no. 1, p. 48-71.

Carlston, C. W., 1946, Appalachian drainage and the highland border sediments of the Newark series: Geological Society of America Bulletin, v. 57, p. 997-1031.

Chapman, R. W., 1965, Stratigraphy (sic) and petrology of the Hampden Basalt in central Connecticut: Connecticut Geological and Natural History Survey Report of Investigations, No. 3, 38 p.

Cook, G. H., 1868, Geology of New Jersey: Newark, New Jersey, 899 p.

Cook, G. H., 1879, Red sandstone or Triassic Formation: New Jersey Geological Survey State Geologist Annual Report for 1879, p. 18-35.

Cook, G. H., 1882, Red sandstone district: New Jersey Geological Survey State Geologist Annual Report for 1882, p. 11-66.

Cook, G. H., 1885, Water wells: New Jersey Geological Survey State Geologist Annual Report for 1885, p. 115-116.

Cook, G. H., 1887, Triassic: New Jersey Geological Survey State Geologist Annual Report for 1886, p. 123-127.

Cook, G. H., 1888, Report of the sub-Committee on Mesozoic, p. 257-258 in Hall, James, chm., Report of the American Committee to the London Session, International Geological Congress: American Geologist, v. 2, p.

Cook, G. H., 1889, On the Triassic or Red Sandstone rocks: New Jersey Geological Survey, State Geologist, Annual Report for 1888, p. 11-44.

Cooper, M. A., and Williams, G. D., eds., 1989, Inversion tectonics: Papers presented at a meeting on Inversion Tectonics held 03-04 March 1987 at the Royal Society of London: Geological Society of London Special Publication No. 44, 375 p. Oxford-London-Edinburgh-Boston-Melbourne, Blackwell Scientific Publications for the Geological Society.

Cornet, Bruce, 1977 ms., The palynostratigraphy and age of the Newark Supergroup: University Park, PA, Pennsylvania State University Department of Geology Ph. D. dissertation, 506 p.

Cornet, Bruce; and Traverse, Alfred, 1975, Palynological contributions to the chronology (sic) and stratigraphy of the Hartford Basin in Connecticut and Massachusetts, p. 1-33 in Geoscience and Man: American Association of Stratigraphic Palynologists Annual Meeting, 6th, Proceedings, v. 11,

Cornet, Bruce; Traverse, Alfred; and MacDonald, N. G., 1973, Fossil spores, pollen and fishes from Connecticut indicate early Jurassic age for part of the Newark Group: Science, v. 182, p. 1243-1247.

Cousminer, H. L.; and Manspeizer, Warren, 1976, Triassic pollen date Moroccan High Atlas and the incipient rifting of Pangaea as Middle Carnian: Science, v. 191, p. 943-944.

Coward, M. P., 1986, Heterogeneous stretching, simple shear and basin develpment: Earth and Planetary Science Letters, v. 80, p. 325-336.

Coward, M. P., 1992, Structural interpretation with emphasis on extentional tectonics: Japec Course No. 122.

Coward, M. P., 1994, Inversion tectonics, Ch. 14, p. 289-304 in Hancock, P. L., ed., Continental deformation: Oxford-New York-Seoul-Tokyo, Pergamon Press, 421 p.

Crespi, J. M., 1988, Using balanced cross sections to understand Early Mesozoic extensional faulting, p. 220-229 in Froelich, A. J., and Robinson, G. R., Jr., eds., Studies of the Early Mesozoic basins of the eastern United States: U. S. Geological Survey Bulletin 1776, 423 p.

Crowell, J. C., 1974, Origin of the late Cenozoic basins in southern California, p. 190-204 in Dickinson, W. R., ed., Tectonics and sedimentation: Tulsa, OK, Society of Economic Paleontologists and Mineralogists Special Publication No. 22, 204 p.

Dallmeyer, R. D., 1975, The Palisades sill: a Jurassic intrusion (sic)? Evidence from 40Ar/39Ar incremental release (sic) ages: Geology, v. 3, p. 243-245.

Darton, N. H., 1889, On the great lava flows and intrusive trap sheets of the Newark system in New Jersey: American Journal of Science, 3rd series, v. 38, p. 134-139.

Darton, N. H., 1890, The relations (sic) of the traps of the Newark system in the New Jersey region: U. S. Geological Survey Bulletin 67, 82 p.

Darton, N. H., 1902, Juratrias rocks, p. 6-10 in Merrill, F. J. H., and others, Description of the New York City district [N. Y.- N. J]: U. S. Geological Survey Geologic Atlas of the United States, New York City Folio 83, 19 p. (maps).

Darton, N. H., 1909, Newark group, p. 7-8 in Bascom, Florence; and others, 1909, Decription of the Philadelphia district: U. S. Geological Survey Geologic Atlas of the United States, Philadelphia Folio No. 162.

Darton, N. H., and Kümmel, H. B., 1908, Newark system, p. 7-13 in
Darton, N. H., Bayley, W. S., Salisbury, R. D., and Kümmel, H. B., 1908, Decription of the Passaic quadrangle: U. S. Geological Survey Geologic Atlas of the United States Passaic Folio No. 157, 27 p., 4 maps.

Davis, W. M., 1882a, Brief notice of observations on the Triassic trap rocks of Massachusetts, Connecticut and New Jersey: American Journal of Science, 3rd series, v. 24, p. 345-349.

Davis, W. M., 1882b, The structural value of the trap ridges of the Connecticut Valley: Boston Society of Natural History Proceedings, v. 22, p. 116-124.

Davis, W. M., 1883, On the relations (sic) of the Triassic traps and sandstones of the eastern United States: Harvard College Museum of Comparative Zoology Bulletin, v. 7 (1880-1884), p. 249-309.

Davis, W. M., 1886, The structure of the Triassic formation of the Connecticut valley: American Journal of Science, 3rd series, v. 32, p. 342-353.

Davis, W. M., 1888a, The structure of the Triassic formation of the Connecticut Valley, p. 455-490 in United States Geological Survey Annual Report, 7th (1885-1886), xxx p.

Davis, W. M., 1888b, Remarks on the mechanical origin of the Triassic monoclinal in the Connecticut valley: Boston Society of Natural History Proceedings, v. 23, p. 339-341.

Davis, W. M., 1889a, The faults in the Triassic formation near Meriden, Conn. A week's work in the Harvard summer school of geology: Cambridge, MA, Harvard College Museum of Comparative Zoology Bulletin, v. 16, p. 61-87.

Davis, W. M., 1896, The quarries in the lava (sic) beds at Meriden, Connecticut: American Journal of Science, 4th series, v. 1, p. 1-13 (map).

Davis, W. M., 1898, The Triassic formation of Connecticut: U. S. Geological Survey Annual Report, 18th, Part 2, p. 1-192. (Agglomerates on p. 62-67).

Davis, W. M., and Whittle, C. L., 1889, The intrusive (sic) and extrusive trap sheets in the Connecticut Valley: Harvard College Museum of Comparative Zoology Bulletin, v. 16, no. 6, p. 99-138 (Geology series, v. 2). (The co-author's name is Whittle, not Whipple, as in Emerson and J. V. Lewis citations.)

Davison, I., 1986, Listric normal fault (sic) profiles: Calculation using bed-length balance and fault displacement: Journal of Structural Geology, v. 8, p. 209-210.

Davison, I., 1989, Extensional domino fault (sic) tectonics: Kinematics and geometrical constraints: Ann. Tecton., v. 3, p. 12-24.

Davison, I., 1994, Linked fault systems; extensional, strike-slip (sic) , and contractional, Ch. 6, p. 121-142 in Hancock, P. L., ed., Continental deformation: Oxford-New York-Seoul-Tokyo, Pergamon Press, 421 p.

de Boer, J. Z., 1968, Paleomagnetic differentiation and correlation of the Late (sic) Triassic volcanic rocks in the central Appalachians (with special reference to the Connecticut Valley: Geological Society of America Bulletin, v. 79, p. 609-626.

de Boer, J. Z., and Clifford, A. E., 1988, Mesozoic tectogenesis: development and deformation of 'Newark' rift zones in the Appalachians (with special emphasis on the Hartford Basin, Connecticut), Chapter 11 in Manspeizer, Warren, ed., Triassic-Jurassic rifting, continental breakup and the origin of the Atlantic Ocean and passive margin: Amsterdam, The Netherlands, Elsevier Science Publishers, 998 p. (2 volumes).

de Boer, J. Z., and Snider, F. G., 1979, Magnetic (sic) and chemical variations of Mesozoic diabase dikes from eastern North America: Evidence for a hotspot in the Carolinas?: Geological Society of America Bulletin, v. 90, p. 185-198.

Dean, W. E., 1988, Inorganic geochemistry of fine-grained sedimentary rocks and hornfels in the Newark Supergroup, p. 79-86 in Froelich, A. J.; and Robinson, G. R., Jr., eds., Studies of the Early Mesozoic basins of the eastern United States: U. S. Geological Survey Bulletin 1776, 423 p.

Degens, E. T., von Herzen, R. P., and Wong, H., 1971, Lake Tanganyika; water chemistry, sediments, geological structure: Naturwissenschaften, v. 58, p. 229-241.

Dennis, J. G., 1987, Structural geology. An introduction: Dubuque, IA, Wm. C. Brown Publishers, 448 p.

Dewey, J. F., and Bird, J. M., 1970, Mountain belts and the new global tectonics: Journal of Geophysical Research, v. 75, no. 14, p. 2625-2647.

Dietz, R. S., and Holden, J. C., 1967, Miogeoclines in space and time: Journal of Geology, v. 65, p. 566.

Drake, A. A., Jr., 1984, The Reading Prong of New Jersey and eastern Pennsylvania; an appraisal of rock relations (sic) and chemistry of a major Proterozoic terrane in the Appalachians, p. 75-109 in Bartholomew, M. J., ed., The Grenville event in the Appalachians and related topics: Geological Society of America Special Paper 194, 294 p.

Drake, C. L., and Woodward, H. P., 1963, Appalachian curvature, wrench faulting and offshore structures: New York Academy of Sciences Transactions, Series II, v. 26, p. 48-63.

Dunning, G. R., and Hodych, J. P., 1990, U/Pb zircon and baddelyite ages for the Palisades and Gettysburg sills of the northeastern United States: implications for the age of the Triassic/Jurassic boundary: Geology, v. 18, p. 795-798.

Du Toit, A. L., 1907, Pipe amygdaloids: Geological Magazine, decade 5, v. 14, p. 13-17.

Einsele, G.; and others, 1980, Intrusion of basaltic sills into highly porous sediments, and resulting hydrothermal activity: Nature, v. 283, p. 441-445.

Elliott, C. G.,; and Williams, P. F., 1988, Sediment slump structures: A review of diagnostic criteria and application to an example from Newfoundland: Journal of Structural Geology, v. 10, p. 171-182.

Emerson, B. K., 1897, Diabase pitchstone and mud enclosures of the Triassic trap of New England: Geological Society of America Bulletin, v. 8, p. 59-86.

England, P., 1983, Constraints on extension of continental lithosphere: Journal of Geophysical Research, v. 88, p. 1145-1152.

Erickson, G. P., and Kulp, J. L., 1961a, Potassium argon (sic) dates on basaltic rocks: New York Academy of Sciences Annals, v. 91, article 2, p. 321-323.

Erickson, G. P., and Kulp, J. L., 1961b, Potassium-argon measurements on the Palisades sill, New Jersey: Geological Society of America Bulletin, v. 72, no. 4, p. 649-652.

Evans, J. W., 1925, Regions of tension: Geological Society of London Quarterly Journal, v. 81, part 2, p. lxxx-cxxii.

Fairbridge, R. W., 1972, Climatology of a glacial cycle: Quaternary Research, v. 2, no. 3, p. 283-303.

Fairbridge, R. W., 1976, Effects of Holocene climate change on some tropical geomorphic processes: Quaternary Research, v. 6, p. 529-556.

Falvey, D. A., 1974, The development of continental margins in plate tectonic (sic) theory: Australian Petroleum Exploration Association Journal, 1974, p. 95-106.

Faust, G. T., 1975, A review and interpretation of the geologic setting of the Watchung basalt flows, New Jersey: U. S. Geological Survey Professional Paper 864-A, 42 p.

Faust, G. T., 1978, Joint systems in the Watchung basalt flows, New Jersey. Studies on the Watchung basalt flows of New Jersey: U. S. Geological Survey Professional Paper 864-B, 46 p.

Fedosh, M. S., and Smoot, J. P., 1988, A cored stratigraphic section through the northern Newark basin, New Jersey, p. 19-24 in Froelich, A. J.; and Robinson, G. R., Jr., eds., 1988, Studies of the early Mesozoic basins of the eastern United States: U. S. Geological Survey Bulletin 1776, 423 p.

Fenner, C. N., 1908, Factors indicative of physiographic conditions prevailing at the time of the trap extrusions in New Jersey: Journal of Geology, v. 16, p. 299-327.

Fenner, C. N., 1910, The Watchung basalt and the paragenesis of its zeolites and other secondary minerals: New York Academy of Sciences Annals, v. 20, p. 93-187.

Ferrel, William 1863, On the causes of the annual inundation of the Nile: American Journal of Science, 2nd series, v. 35, p. 62-64.

Fischer, A. G., 1975, Origin (sic) and growth of basins, p. 47-79 in Fischer, A. G.; and Judson, Sheldon, eds., Petroleum and global tectonics: Princeton, NJ, Princeton University Press, 322 p.

Folger, D. W., Dillon, W. P., Grow, J. W., Klitgord, K. D., and Schlee, J. S., 1979, Evolution of the Atlantic continental margin of the United States, p. 87-108 in Talwani, Manik; Hay, W. W.; and Ryan, W. B. F., eds., Deep drilling (sic) results in the Atlantic Ocean; continental margins and paleoenvironment: Maurice Ewing Symposium, 2nd, 19-25 March 1978, Harriman, NY, Proceedings: Washington, D. C., American Geophysical Union Maurice Ewing Series No. 3, 437 p.

Foye, W. G., 1925, Pillow structure in the Triassic basalts of Connecticut: Geological Society of America Bulletin, v. 35, p. 329-346.

Foye, W. G., 1930, A basaltic vent of Triassic age at Durham, Connecticut: American Journal of Science, 5th series, v. 19, p. 151-157.

Foye, W. G., 1936, A spatter cone in the main trap sheet, Farmington, Connecticut: American Journal of Science, 5th series, v. 31, p. 296-300.

Francheteau, F.; and LePichon, Xavier, 1972, Marginal fracture zones as structural framework of continental margins in South Atlantic Ocean: American Association of Petroleum Geologists Bulletin, v. 56, p. 991-1007.

Frazer, Persifor, Jr., 1875, On the Mesozoic Red Sandstone of the Atlantic States: Academy of Natural Sciences (Philadelphia) Proceedings, v. 27, p. 440-442.

Frazer, Persifor, Jr., 1883, Report of a geological survey of Chester County: Geological Survey of Pennsylvania, Second, Report of Progress CCCC: Harrisburg, Pennsylvania, 394 p.

Friedman, G. M., and Sanders, J. E., 1982, Time-temperature-burial significance of Devonian anthracite implies former great (~6.5 km) depth of burial of Catskill Mountains, New York: Geology, v. 10, no. 2, p. 93-96. (Also, reply to discussion, 1983, ibid., v. 11, no. 2, p. 123-124.

Friedman, G. M., Sanders, J. E., and Kopaska-Merkel, D. C., 1992, Principles of sedimentary deposits. Stratigraphy and sedimentology: New York, NY, Macmillan Publishing Company, 717 p.

Froelich, A. J., and Olsen, P. E., 1985, 1. Newark Supergroup, a revision of the Newark Group in eastern North America, p. 1-3 in Robinson, G. R., and Froelich, A. J., eds., U. S. Geological Survey workshop on the Early Mesozoic basins of the eastern United States, Second, Proceedings: U. S. Geological Survey Circular 946, 147 p.

Froelich, A. J.; and Gottfried, David, 1985, Early (sic) Jurassic diabase sheets of the eastern United States--a preliminary overview. Section 15, p. 79-86 in Robinson, G. R., and Froelich, A. J., eds., U. S. Geological Survey workshop on the Early Mesozoic basins of the eastern United States, Second, Proceedings: U. S. Geological Survey Circular 946, 147 p.

Fuller, R. E., 1927, The closing phase of a fissure eruption: American Journal of Science, 5th series, v. 14, p. 228-230.

Fuller, R. E., 1931, The aqueous chilling of basaltic lavas on the Columbia Plateau: American Journal of Science, 5th series, v. 21, p. 281-300.

Gibbs, A. D., 1983, Balanced cross-section construction from seismic lines in areas of extensional tectonics: Journal of Structural Geology, v. 5, p. 153-160.

Gibbs, A. D., 1984, Structural evolution of extensional basin (sic) margins: Geological Society of London Journal, v. 141, p. 609-620.

Gibbs, A. D., 1990, Linked fault (sic) families in basin formation: Journal of Structural Geology, v. 12, p. 795-803.

Gibson, J. R.; Walsh, J. J.; and Watterson, J., 1989, Modelling of bed contours and cross-sections (sic) adjacent to planar normal faults: Journal of Structural Geology, v. 11, p. 317-328.

Gilchrist, R.; Coward, M. P.; and Mugnier, J. L., 1987, Structural inversion, examples from the Alpine Foreland and the French Alps: Geodinimca Acta, v. 1, p. 5-34.

Gordon, R. G., Cox, A., and O' Hare, S., 1984, Paleomagnetic Euler poles and the apparent polar wander and absolute motion of North America since the Carboniferous: Tectonics, v. 3, p. 499-537.

Green, P. F., 1986, On the thermal tectonic evolution of Northern England; evidence from fission track (sic) analysis: Geological Magazine, v. 123, p. 493-506.

Greenland Ice-core Project (GRIP) Members, 1993, Climate instability during the last interglacial period recorded in the GRIP ice core: Nature, v. 364, p. 203-207.

Grootes, P. M.; Stuiver, Minze; White, J. W. C.; Johnsen, S; and Jouzel, J., 1993, Comparison of oxygen isotope (sic) records from the GISP2 and GRIP Greenland ice cores: Nature, v. 366, p. 552-554.

Groshong, R. H., 1989, Half-graben structures: Balanced models of extensional fault-bend folds: Geological Society of America Bulletin, v. 101, p. 96-105.

Gutenberg, Beno, 1941, Changes in sea level, postglacial uplift, and mobility of the Earth's interior: Geological Society of America Bulletin, v. 52, p. 721-772.

Hall, L. M., 1968a, Geology in the Glenville area, southwesternmost Connecticut and southeastern New York, Trip D-C, p. 1-12 in Orville, P. M., ed., Guidebook for field trips in Connecticut: New England Intercollegiate Geological Conference, Annual Meeting, 60th, New Haven, Connecticut.

Hall, L. M., 1968b, Times of origin and deformation of bedrock in the Manhattan Prong, p. 117-127 in Zen, Ean; White, W. S.; Hadley, J. B.; and Thompson, J. B., Jr., eds., Studies of Appalachian geology, northern and maritime: New York, Wiley-Interscience Publishers, 475 p.

Harding, T. P., 1983, Seismic characteristics (sic) and identification of negative flower structures, positive flower stuructes and positive structural inversion (sic): American Association of Petroleum Geologists Bulletin, v. 69, p. 582-600.

Hatcher, R. D., Jr., 1990, Structural geology. Principles, concepts, and problems: Columbus-Toronto-London-Melbourne, Merrill Publishing Co., 531 p.

Hawes, G. W., 1875a, The trap rocks of the Connecticut Valley: American Journal of Science, 3rd series, v. 9, p. 185-192.

Hawes, G. W., 1875b, On diabantite, a chlorite occurring in the trap of the Connecticut valley: American Journal of Science, 3rd series, v. 9, p. 454-457.

Hawes, G. W., 1876, The rocks of the "chloritic formation" on the western border of the New Haven region: American Journal of Science, 3rd series, v. 11, p. 122-126.

Hawkins, A. C., 1914, Lockatong formation of the Triassic of New Jersey and Pennsylvania: New York Academy of Sciences Annals, v. 23, p. 145-176.

Hawkins, A. C., 1928, Halite (sic) and glauberite cavities and included minerals from central New Jersey: American Mineralogist, v. 13, p. 238.

Hayward, A. B., and Graham, R. H., 1989, Some geometrical characteristics of inversion, p. 17-39 in Cooper, M. A., and Williams, G. D., eds., Inversion tectonics: Papers presented at a meeting on Inversion Tectonics held 03-04 March 1987 at the Royal Society of London: Geological Society of London Special Publication No. 44, 375 p. Oxford-London-Edinburgh-Boston-Melbourne, Blackwell Scientific Publications for the Geological Society.

Henderson, J. F., 1953, The formation of pillow lavas and breccias: Royal Society of Canada Transactions, 3rd series, section 4, v. 47, p. 23-32.

Henderson, J. R., Andreasen, G. E., and Petty, A. J., 1966, Aeromagnetic map of northern New Jersey and adjacent parts of New York and Pennsylvania: U. S. Geological Survey Geophysical Investigations, Map GP-562 (scale 1:125,000).

Hess, H. H., 1956, The magnetic properties and differentiation of dolerite sills - a critical discussion: American Journal of Science, v. 254, p. 446-451.

Hitchcock, Edward, 1853 [Address on fossil foot-marks in Connecticut Valley]: Boston Society of Natural History Proceedings, v. 4, p. 378-379.

Hitchcock, Edward, 1858, Ichnology of New England. A report on the sandstone of the Connecticut Valley, especially its fossil footmarks: Boston, MA, William White, 220 p.

Hotz, P. E., 1952, The form of diabase sheets in southeastern Pennsylvania: American Journal of Science, v. 250, p. 375-388.

Hovey, E. O., 1889, Observations on some of the trap ridges of the East Haven-Branford region: American Journal of Science, 3rd series, v. 38, p. 361-383.

Hs , K. J., 1958, Isostasy and a theory (sic) for the origin of geosynclines: American Journal of Science, v. 256, p. 305-327.

Hs , K. J., 1965, Isostasy, crustal thinning, mantle changes, and the disappearance of ancient landmasses: American Journal of Science, v. 263, p. 97-109.

Huang, Q., 1988, Geometry (sic) and tectonic significance of Albian sedimentary dykes in the Sisteron area, SE France: Journal of Structural Geology, v. 10, p. 453-462.

Hubert, J. F., 1978, Paleosol caliche in the New Haven Arkose, Newark Group, Connecticut: Palaeogeography, Palaeoclimatology, and Palaeoecology, v. 24, p. 151-168.

Hubert, J. F., Reed, A. A., Dowdall, W. L., and Gilchrist, J. M., 1978, Guidebook to Mesozoic redbeds of central Connecticut: Connecticut Geological and Natural History Survey Guidebook No. 4, 129 p. (reprint from Society of Economic Mineralogists and Paleontologists, Eastern Section Guidebook).

Husch, J. M., 1988, Significance of major- and trace-element variation trends in Mesozoic diabase, west-central New Jersey and eastern Pennsylvania, p. 141-150 in Froelich, A. J.; and Robinson, G. R., Jr., eds., 1988, Studies of the early Mesozoic basins of the eastern United States: U. S. Geological Survey Bulletin 1776, 423 p.

Husch, J. M., 1990, Palisades sill: Origin of the olivine zone by separate magmatic injection rather than gravity settling: Geology, v. 18, p. 699-702.

Husch, J. M., Sturgis, D. S., and Bambrick, T. C., 1984, Mesozoic diabases from west-central New Jersey; major (sic) and trace element (sic) geochemistry of whole rock (sic) samples: Northeastern Geology, v. 6, no. 1, p. 51-63.

Hutchinson, D. R., and Klitgord, K. D., 1988a, Deep structure of rift basins from the continental margin around New England, p. 211-219 in Froelich, A. J.; and Robinson, G. R., Jr., eds., Studies of the Early Mesozoic basins of the eastern United States: U. S. Geological Survey, Bulletin 1776, 423 p.

Hutchinson, D. R., and Klitgord, K. D., 1988b, Evolution of rift basins on the continental margin off southern New England, Chapter 4 in Manspeizer, Warren, ed., Triassic-Jurassic rifting, continental breakup and the origin of the Atlantic Ocean and passive margin: Amsterdam, The Netherlands, Elsevier Science Publishers, 998 p. (2 volumes).

Iddings, J. P., 1886, The columnar structure in the igneous rocks on Orange Mountain New Jersey: American Journal of Science, 3rd series, v. 35, p. 321-330.

Irving, E., and Irving, G. A., 1982, Apparent polar wander paths Carboniferous through Cenozoic and the assembly of Gondwana: Geophysical Surveys, v. 5, p. 141-188.

Jarvis, G. T., 1984, An extensional model of graben subsidence--the first stage of basin evolution: Sedimentary Geology, v. 40, p. 13-31.

Jarvis, G. T., and McKenzie, D. P., 1980, Sedimentary basin (sic) formation with finite extension rates: Earth and Planetary Science Letters, v. 48, p. 42-52.

Johnsen, S. J., and nine others, 1992, Irregular glacial interstadials recorded in a new Greenland ice core: Nature, v. 359, p. 311-313.

Johnson, D. W., 1931, Stream sculpture on the Atlantic slope, a sutdy in the evolution of Appalachian Rivers: New York, NY, Columbia University Press, 142 p.

Johnson, M. E., and McLaughlin, D. B., 1957, Triassic formations in the Delaware Valley, p. 31-68 in Dorf, Erling, ed., Geological Society of America Annual Meeting, Atlantic City 1957, Guide-book for Field Trips: Guidebook Series, 280 p.

Jones, M. E., and Addis, M. A., 1984, Volume change during sediment diagenesis and the devlopment of growth faults: Marine and Petroleum Geology, v. 1, p. 118-122.

Jones, M. E., and Addis, M. A., 1985, On the changes in porosity and volume (sic) during a burial of argillaceous sediments: Marine and Petroleum Geology, v. 2, p. 247-252.

Jones, M. E., and Addis, M. A., 1986, The application of stress path (sic) and critical state (sic) analysis to sediment deformation: Journal of Structural Geology, v. 8, p. 575-580.

Justus, P. S., and Weigand, P. W., 1971, Distribution of dolerite magma types and variations of dike-swarm pattern: clues to tectonic history of Appalachians in Early Mesozoic: Pennsylvania Academy of Science Proceedings, v. 45, p. 202-203.

Keen, C. E., 1987, Some important consequences of lithospheric extension, p. 57-73 in Coward, M. P.; Dewey, J. F.; and Hancock, P. L., eds., Continental extensional tectonics: London, UK, Geological Society of London Special Publication 28, xxx p.

Keller, G. R., and Hoover, J. D., 1988, A comparison of the Newark and Rio grande rift systems and associated magmatism, Chapter 37 in Manspeizer, Warren, ed., Triassic-Jurassic rifting, continental breakup and the origin of the Atlantic Ocean and passive margin: Amsterdam, The Netherlands, Elsevier Science Publishers, 998 p. (2 volumes).

Kingston, D. R., Dishroon, C. P., and Williams, P. A., 1983, Global basin classification (sic) system: American Association of Petroleum Geologists Bulletin, v. 67, no. 12, p. 2175-2193.

Kinsman, D. J. J., 1975, Rift valley (sic) basins and sedimentary history of trailing continental margins, p. 83-126 in Fischer, A. G.; and Judson, Sheldon, eds., Petroleum and global tectonics: Princeton, NJ, Princeton University Press, 322 p.

Klemperer, S., 1988, Crustal thinning and nature of extension in the northern North Sea from deep seismic reflection (sic) profiling (sic): Tectonics, v. 7, p. 803-822.

Klitgord, K. S., and Behrendt, J. D., 1979, Basin structure of the U. S. continental margin, p. 85-112 in Watkins, J. S.; Montadert, L.; and Dickerson, P. W., eds., Geological (sic) and geophysical investigations of the continental margins: Tulsa, OK, American Association of Petroleum Geologists Memoir 29, 801 p.

Klitgord, K. S., and Hutchinson, D. R., 1985, Distribution and geophysical signatures of early Mesozoic rift basins beneath the U. S. Atlantic continental margin, Chapter 9, p. 45-53 in Robinson, G. R., Jr.; and Froelich, A. J., eds., U. S. Geological Survey workshop on the Early Mesozoic basins of the eastern United States, Second, Proceedings: U. S. Geological Survey Circular 946, 147 p.

Kümmel, H. B., 1897, The Newark System, report of progress: New Jersey Geological Survey State Geologist Annual Report for 1896, p. 25-88.

Kümmel, H. B., 1898, The Newark System, or Red Sandstone belt: New Jersey Geological Survey State Geologist Annual Report for 1897, p. 23-159.

Kümmel, H. B., 1899a, The Newark rocks of New Jersey and New York: Journal of Geology, v. 7, p. 23-52.

Kümmel, H. B., 1899b, The extension of the Newark system of rocks: New Jersey Geological Survey State Geologist Annual Report for 1901, p. 43-57.

Kümmel, H. B., 1914, Triassic rocks, p. 13-16, 20 in Bayley, W. S., Salisbury, R. D., and Kümmel, H. B., Description of the Raritan quadrangle, New Jersey: United States Geological Survey Geologic Atlas of the United States Raritan Folio, No. 191, 32 p. (maps)

Kümmel, H. B., 1933, Glacial history of the Passaic Valley and related glacial features, p. 64-77 in Berkey, C.P., ed., New York City and vicinity: International Geological Congress, 16th, United States, Guidebook 9, New York excursions: Washington, D. C., U. S. Government Printing Office, 151 p.

Kümmel, H. B., 1940, The geology of New Jersey: Trenton, NJ, New Jersey Department of Conservation and Development, Geological Series, Bulletin 50, 203 p.

LaGanza, R. F., 1960, Paragenetic relationships of deuteric minerals in the Triassic dolerites near New Haven, Connecticut: Neues Jahrbuch fur Mineralogie, Abhandlungen, v. 94 (Festband Paul Ramdohr), part 1, p. 559-563.

LASE Study Group, 1986, Deep structure of the U. S. east coast margin from Large Aperture (sic) Seismic Experiments (LASE): Marine and Petroleum Geology, v. 3, p. 234-242.

Leeder, M. R., and Gawthorpe, R. L., 1987, Sedimentary models for extensional tilt-block/half-graben basins, p. 139-152 in Coward, M. P.; Dewey, J. F.; and Hancock, P. L., eds., Continental extensional tectonics: London, UK, Geological Society of London Special Publication No. 28, 637 p.

Lehmann, E. P., 1959, The bedrock geology of the Middletown quadrangle: Connecticut Geological and Natural History Survey Quadrangle Report No. 8, 40 p.

LePichon, Xavier; and Sibuet, J.-C., 1981, Passive margins: a model of formation: Journal of Geophysical Research, v. 86, p. 3708-3720.

Levorsen, A. I., 1933, Studies in paleogeology: American Association of Petroleum Geologists Bulletin, v. 17, no. 9, p. 1107-1132.

Levorsen, A. I., 1934, Relation (sic) of oil (sic) and gas pools to unconformities in the Mid-Continent region, p. 761-784 in Wrather, W. E., and Lahee, F. H., eds., Problems of petroleum geology--a symposium (Sydney Powers memorial volume): Tulsa, OK, American Association of Petroleum Geologists, 1073 p.

Levorsen, A. I., 1943, Discovery thinking: American Association of Petroleum Geologists Bulletin, v. 27, p. 887-928.

Levorsen, A. I., 1945, Time of oil (sic) and gas accumulation: American Association of Petroleum Geologists Bulletin, v. 29, p. 1189-1194.

Levorsen, A. I., 1948, Our petroleum resources: Geological Society of America Bulletin, v. 50, no 4, p. 283-299.

Levorsen, A. I., 1954, Geology of petroleum: San Francisco, CA, W. H. Freeman and Company, 703 p.

Levorsen, A. I., 1960, Paleogeologic maps: San Francisco, CA, W. H. Freeman and Company, 174 p.

Levorsen, A. I., 1964, Big geology for big needs: American Association of Petroleum Geologists Bulletin, v. 48, no. 2, p. 141-156.

Lewis, J. V., 1907a, The double crest of Second Watchung Mountain: Journal of Geology, v. 15, p. 39-45.

Lewis, J. V., 1907b, The origin and relations (sic) of the Newark Rocks, Part III, p. 99-129 in Geological Survey of New Jersey Annual Report of the State Geologist for the year 1906: Trenton, NJ, MacCrellish & Quigley, State Printers, 192 p.

Lewis, J. V., 1907c, Properties of trap rocks for road construction, Part III, p. 165-172 in Geological Survey of New Jersey Annual Report of the State Geologist for the year 1906: Trenton, NJ, MacCrellish & Quigley, State Printers, 192 p.

Lewis, J. V., 1908a, Petrography of the Newark igneous rocks of New Jersey. Part IV, p. 97-167 in Geological Survey of New Jersey Annual Report of the State Geologist for the year 1907: Trenton, NJ, The John L. Murphy Publishing Company, Printers, 192 p.

Lewis, J. V., 1908b, The Palisades diabase of New Jersey: American Journal of Science, v. 176, p. 155-162.

Lewis, J. V., 1914, Origin of pillow lavas (sic): Geological Society of America Bulletin, v. 25, p. 591-654 (Massachusetts and Connecticut, p. 621-622).

Lewis, J. V., 1915a, Origin of the secondary minerals of the Triassic trap rocks: New Jersey Geological Survey Bulletin 16, p. 45-49.

Lewis, J. V., 1915b, The pillow lavas (sic) of the Watchung Mountains: New Jersey Geological Survey Bulletin 16, p. 51-56.

Lindholm, R. C., 1978a, Tectonic control of sedimentation in Triassic-Jurassic Culpeper basin, Virginia (abstract): American Association of Petroleum Geologists Bulletin, v. 62, p. 537 (only).

Lindholm, R. C., 1978b, Triassic-Jurassic faulting in eastern North America--a model based on pre-Triassic structures: Geology, v. 6, no. 6, p. 365-368.

Lobeck, A. K., 1918, The superb position of New York City as a center for physiographic study: New York Academy of Sciences Annals, v. 28, p. 1-50.

Lobeck, A. K., 1952, Panoramic view of the New York region as seen from the Palisades: New York, NY, Columbia University, Scenic Folder No. 1 (folded sheet).

Lobeck, A. K., and Raisz, E. J., 1930, The physiography of the New York region: New York, New York, Columbia University, The Geographical Press, 8 p. (with sketches by R. L. Dickinson).

Longwell, C. R., 1922, Notes on the structure of the Triassic rocks in southern Connecticut: American Journal of Science, 5th series, v. 4, p. 233-236.

Longwell, C. R., 1928, The Triassic of Connecticut: American Journal of Science, 5th series, v. 16, p. 259-263.

Longwell, C. R., 1933, The Triassic belt of Massachusetts and Connecticut, p. 93-118 in Longwell, C. R. ed., Eastern New York and western New England: International Geological Congress, 16th, United States 1933, Guidebook 1, Excursion A-1: Washington, D. C., U. S. Government Printing Office, 118 p.

Longwell, C. R., 1943, Geologic interpretation of gravity anomalies in the southern New England-Hudson Valley region: Geological Society of America Bulletin, v. 54, p. 555-590.

Longwell, C.R., 1937, Sedimentation in relation to faulting: Geological Society of America Bulletin, v. 48, p. 433-442.

Lovegreen, J. R., 1974 ms., Paleodrainage history of the Hudson Estuary: New York, NY, Columbia University Department of Geological Sciences Master's Thesis, 151 p., 8 pl.

Lowe, K. E., 1959, Structure of the Palisades intrusion (sic) at Haverstraw and West Nyack, New York, p. 1127-1139 in Lowe, K. E., Chm. and Consulting Ed., Modern aspects of the geology of New York City and environs: New York Academy of Sciences Annals, v. 80, art 4, p. 1047-1170.

Lucas, M., and others, 1988, A foreland-type fold and related structures in the Newark rift basin, Chapter 12 in Manspeizer, Warren, ed., Triassic-Jurassic rifting, continental breakup and the origin of the Atlantic Ocean and passive margin: Amsterdam, The Netherlands, Elsevier Science Publishers, 998 p. (2 volumes).

Luttrell, G. L., 1989, Stratigraphic nomenclature of the Newark Supergroup of eastern North America: U. S. Geological Survey Bulletin 1572, 136 p.

Lyman, B. S., 1893, The great Mesozoic fault in New Jersey: American Philosophical Society Proceedings, v.31, p. 314-317.

Lyman, B. S., 1894, Some New Red horizons: American Philosophical Society Proceedings, v. 33, p. 192-215.

Lyman, B. S., 1895, Report on the New Red of Bucks and Montgomery counties: Geological Survey of Pennsylvania, Second: A summary description of the geology of Pennsylvania, v. 3, part 2, p. 2589-2638.

Lyttle, P. T., and Epstein, J. B., 1987, Geologic map of the Newark 1° by 2° quadrangle, New Jersey, Pennsylvania, and New York: United States Geological Survey Miscellaneous Investigations Series Maps, Map I-1715 (2 sheets; scale 1:250,000).

MacDonald, W. D., 1972, Continental crust, crustal evolution, and the Caribbean, p. 351-362 in Shagam, R.; Hargraves, R. B.; Morgan, W. J.; van Houten, F. B.; Burk, C. A.; Holland, H. D.; and Hollister, L. C., eds., Studies in Earth and space sciences: Geological Society of America Memoir 132, 685 p.

MacKenzie, D. P., 1967, Some remarks on heat flow and gravity anomalies: Journal of Geophysical Research, v. 72, p. 6261-6273.

MacKenzie, D. P., 1978, Some remarks on the development of sedimentary basins: Earth and Planetary Science Letters, v. 40, p. 25-32.

MacKenzie, D. P., and Sclater, J. G., 1971, The evolution of the Indian Ocean since the late Cretaceous: Royal Astronomical Society Geophysical Journal, v. 25, p. 437-528.

MacKenzie, D. P.; Davies, D.; and Molnar, P., 1970, Plate tectonics of the Red Sea and East Africa: Nature, v. 226, p. 243-248.

Mandl, G.; and Crans, W., 1981, Gravitational gliding in deltas, p. 41-54 in McClay, K. R., and Price, N. J., eds., Thrust (sic) and nappe tectonics: Geological Society of London Special Publication No. 9, 539 p. (Published for the Geological Society of London by Blackwell Scientific Publications, Oxford-London-Edinburgh-Boston-Melbourne.)

Mann, P.; Hempton, M. R.; Bradley, D. C.; and Burke, K., 1983, Development of pull-apart basins: Journal of Geology, v. 91, p. 529-554.

Manspeizer, Warren, 1969, Paleoflow structures in Late (sic) Triasic basaltic lava (sic) of the Newark Basin and their regional implications (abstract): Geological Society of America, Abstracts With Programs for 1969, part 7, p. 142 (only).

Manspeizer, Warren, 1980, Rift tectonics inferred from volcanic (sic) and clastic structures, p. 314-350 in Manspeizer, Warren, ed., Field studies in New Jersey geology and guide to field trips: New York State Geological Association, 52nd, October 1980, Newark, New Jersey, Guidebook: Newark, New Jersey, Rutgers University, Newark College of Arts and Sciences, 398 p.

Manspeizer, Warren, 1981, Early Mesozoic basins of the central Atlantic passive margins, p. 4-1 to 4-60 in Bally, A. W., ed., Geology of passive continental margins: history, structure,and sedimentologic record (with special emphasis on the Atlantic margins): Tulsa, OK, American Association of Petroleum Geologists Education Course Note Series, No. 19.

Manspeizer, Warren, 1988b, Triassic-Jurassic rifting and opening of the Atlantic: an overview, Chapter 3, in Manspeizer, Warren, ed., Triassic-Jurassic rifting, continental breakup and the origin of the Atlantic Ocean and passive margin: Amsterdam, The Netherlands, Elsevier Science Publishers, 998 p. (2 volumes).

Manspeizer, Warren, ed., 1988a, Triassic-Jurassic rifting, continental breakup and the origin of the Atlantic Ocean and passive margin: Amsterdam, The Netherlands, Elsevier Science Publishers, 998 p. (2 volumes).

Manspeizer, Warren, 1994, Multiple tectonic inversions of east coast (sic) Mesozoic rift basins: case study from the Durham Basin, N. C. (abstract): Geological Society of America Abstracts with Programs, v. 26, no. 3, p. 58 (only).

Manspeizer, Warren; and Cousminer, H. L., 1976, Crustal thinning: A precursor to the break-up (sic) of Pangaea and the opening of the Atlantic Ocean (abstract): Geological Society of America Abstracts With Programs, v. 8, p. 995-996.

Manspeizer, Warren; Cousminer, H. L.; and Puffer, J. L., 1978, Separation of Morocco and eastern North America: a Triassic-Liassic stratigraphic record: Geological Society of America Bulletin, v. 89, p. 910-920.

Manspeizer, Warren; and Gates, A. E., 1995, Episodic rifting and basin inversion: Permo-Triassic events (abstract): Geological Society of America Abstracts with Programs, v. 27, no. 1, p. 66-67.

Margolis, Jacob; Robinson, G. R., Jr.; and Schafer, C. M., 1986, Annotated bibliography of studies of the geology (sic), geochemistry (sic) mineral resources (sic), and geophysical character (sic) of the Early Mesozoic basins of the eastern United States, 1880-1984: U. S. Geological Survey Bulletin 1688, 492 p.

Marshall, J. E., ed., 1987, Diagenesis of sedimentary sequences: London, UK, Geological Society of London Special Publications No. 36, 360 p.

Martinsen, O. J., 1987, Styles of soft-sediment deformation on a Namurian (Carboniferous) delta slope, Western Irish Namurian Basin, Ireland, p. 167-178 in Whateley, M. K. G.; and Pickering, K. T., eds., Deltas, sites (sic) and traps for fossil fuels: London, UK, Geological Society of London Special Publication No. 41, 360 p.

Martinsen, O. J.; and Bakke, B., 1990, Extensional (sic) and compressional zones in slumps and slides in the Namurian of County Clare, Ireland: Geological Society of London Journal, v. 147, p. 153-164.

Mason, B. H., 1960, Trap rock minerals of New Jersey: New Jersey Geological Survey Bulletin 64, 51 p.

May, P. R., 1971, Pattern of Triassic-Jurassic diabase dikes around the North Atlantic in the context of predrift position of the continents: Geological Society of America Bulletin, v. 82, p. 1285-1292.

McHone, J. G., 1988, Tectonic (sic) and paleostress patterns of Mesozoic intrusions (sic) in eastern North America, Chapter 25 in Manspeizer, Warren, ed., Triassic-Jurassic rifting, continental breakup and the origin of the Atlantic Ocean and passive margin: Amsterdam, The Netherlands, Elsevier Science Publishers, 998 p. (2 volumes).

McHone, J. R., and Butler, J. R., 1984, Mesozoic igneous provinces and the opening of the North Atlantic Ocean: Geological Society of America Bulletin, v. 95, p. 757-765.

McKee, E. D., and others, 1959, Paleotectonic map of the Triassic System: U. S. Geological Survey Miscellaneous Geologic Investigations Map I-300, 33 p.

McLaughlin, D. B., 1959, Ch. 4, Mesozoic rocks, p. 53-114 in Willard, Bradford; Freedman, J.; McLaughlin, D. B.; and others, Geology (sic) and mineral resources of Bucks County, Pennsylvania: Pennsylvania Geological Survey, 4th series, Bulletin C9, 243 p.

Merguerian, Charles, 1983a, Tectonic significance of Cameron's Line in the vicinity of the Hodges Complex--an imbricate thrust (sic) model for western Connecticut: American Journal of Science, v. 283, p. 341-368.

Merguerian, Charles, 1983b, The structural geology of Manhattan Island, New York City (NYC), New York (abstract): Geological Society of America Abstracts With Programs, v. 15, no. 3, p. 169 (only).

Merguerian, Charles; and Baskerville, C. A., 1987, The geology of Manhattan Island and the Bronx, New York City, New York, p. 137-140 in Northeastern Section of the Geological Society of America, Centennial Fieldguide, v. 5, 481 p.

Merguerian, Charles; and Sanders, J. E., 1989, Trip 04: Geology of Staten Island and vicinity, 15 April 1989: New York Academy of Sciences Section of Geological Sciences Trips on the Rocks Guidebook, 49 p.

Merguerian, Charles; and Sanders, J. E., 1990, Trip 14: Geology and history of the Hudson River valley, 28 October 1990: New York Academy of Sciences Section of Geological Sciences Trips on the Rocks Guidebook, 106 p.

Merguerian, Charles; and Sanders, J. E., 1991a, Variations in style of Paleozoic fold-fault deformation in the southern New England Appalachian foreland of New York and New Jersey--a case for basement control of structures (abstract): Geological Society of America, Abstracts with Programs, v. 23, no. 1, p. 103 (only).

Merguerian, Charles; and Sanders, J. E., 1991b, Trip 16: Geology of Manhattan and the Bronx, 21 April 1991: New York Academy of Sciences Section of Geological Sciences Trips on the Rocks Guidebook, 141 p.

Merguerian, Charles; and Sanders, J. E., 1991c, Trip 18: Connecticut mines and dinosaurs, 16 June 1991: New York Academy of Sciences Section of Geological Sciences Trips on the Rocks Guidebook, 91 p.

Merguerian, Charles; and Sanders, J. E., 1991d, Trip 19: Geology of Staten Island and vicinity, 29 September 1991 (revision of 1989 Trip 04, 15 April 1989): New York Academy of Sciences Section of Geological Sciences Trips on the Rocks Guidebook, 78 p.

Merguerian, Charles; and Sanders, J. E., 1992a, Xenoliths as indicators of paleoflow and paleoenvironmental conditions in the Palisades sheet, New York and New Jersey (abstract): Geological Society of America, Abstracts with Programs, v. 24, no. 3, p. 62-63.

Merguerian, Charles; and Sanders, J. E., 1994a, Danbury anticline of Sanders (1960) revisited: Postdepositional structural explanation for northeast end of Newark Basin, Rockland County, NY (abstract): Geological Society of America Abstracts with Programs, v. 26, no. 3, p. 62 (only).

Merguerian, Charles; and Sanders, J. E., 1994b, Post-Newark folds and -faults: implications for the geologic history of the Newark Basin (extended abstract), p. 57-64 in Hanson, G. N., chm., Geology of Long Island and metropolitan New York, 23 April 1994: Stony Brook, NY: Stony Brook, NY, Long Island Geologists Program with Abstracts, 165 p.

Merguerian, Charles; and Sanders, J. E., 1994c, Trip 30: Geology of the Hudson Highlands and Bear Mountain, 21 May 1994: New York Academy of Sciences Section of Geological Sciences Trips on the Rocks Guidebook, 112 p.

Merguerian, Charles; and Sanders, J. E., 1994d, Trip 31: Connecticut mines and dinosaurs, 18 June 1994: New York Academy of Sciences Section of Geological Sciences Trips on the Rocks Guidebook, 111 p.

Merguerian, Charles; and Sanders, J. E., 1994e, Implications of the Graniteville xenolith for flow directions of the Palisades magma (abstract): p. 59 (only) in A. I. Benimoff, ed., The Geology of Staten Island, New York, The Geological Association of New Jersey Annual Meeting 11th, Somerset, NJ, 14-15 October 1994, Field guide and proceedings, 296 p.

Merguerian, Charles; and Sanders, J. E., 1994e, Trip 33, Staten Island and vicinity, 16 October 1994: New York Academy of Sciences 1994 Trips on the Rocks Guidebook, 151 p.

Merguerian, Charles; and Sanders, J. E., 1995a, NE-, not SE-, (sic) directed paleoflow of the Palisades magma: new evidence from xenoliths and contact relationships (extended abstract): p. 64-77 in Hanson, G. N., chm., Geology of Long Island and metropolitan New York, 22 April 1995: Stony Brook, NY: Stony Brook, NY, Long Island Geologists Program with Abstracts, 135 p.

Merguerian, Charles; and Sanders, J. E., 1995b, Late syn-intrusive clastic dikes at the base of the Palisades intrusive sheet, Fort Lee, NJ, imply a shallow (~3 to 4 km) depth of intrusion (extended abstract): p. 54-63 in Hanson, G. N., chm., Geology of Long Island and metropolitan New York, 22 April 1995: Stony Brook, NY: Stony Brook, NY, Long Island Geologists Program with Abstracts, 135 p.

Miller, B. B. and Puffer, J. H., 1972, The cordierite zone of hornfels near the base of the Palisades Sill at Weehauken, New Jersey (abs.): New Jersey Academy of Sciences Bulletin, v. 17, p. 46.

Morley, C. K.; Nelson, R. A.; Patton, T. L.; and Munn, S. G., 1990, Transfer zones in the East African rift system and their relevance to hydrocarbon exploration in rifts: American Association of Petroleum Geologists Bulletin, v. 74, p. 1234-1253.

Mose, D. G.; and Merguerian, Charles, 1985, Rb-Sr whole-rock age determination on parts of the Manhattan Schist and its bearing on allochthony in the Manhattan Prong, southeastern New York: Northeastern Geology, v. 7, no. 1, p. 20-27.

Mutter, J. C., Buck, W. R., and Zehnder, C. R., 1988, Convective partial melting 1. A model for the formation of thick basaltic sequences during initiation of spreading: Journal of Geophysical Research, v. 93, no. B2, p. 1031-1048.

O'Hara, K., 1986, Tectonic implications of late Paleozoic metamorphism in southeatern New England: Geology, v. 14, p. 430-432.

Olsen, P. E., 1978, On the use of the term Newark for Triassic and Early (sic) Jurassic rocks of eastern North America: Newsletters Stratigraphy, v. 7, no. 2, p. 90-95.

Olsen, P. E., 1980a, The latest (sic) Triassic and Early (sic) Jurassic formations of the Newark basin (eastern North America, Newark Supergroup): Stratigraphy, structure, and correlation: New Jersey Academy of Science Bulletin, v. 25, p. 25-51.

Olsen, P. E., 1980b, Triassic and Jurassic formations of the Newark basin, p. 2-39 in Manspeizer, Warren, ed., Field studies in New Jersey geology and guide to field trips: New York State Geological Association, 52nd, October 1980, Newark, NJ, Guidebook: Newark, New Jersey, Rutgers University, Newark College of Arts and Sciences, 398 p.

Olsen, P. E., 1980c, Fossil great lakes of the Newark Supergroup in New Jersey, p. 352-398 in Manspeizer, Warren, ed., Field studies in New Jersey geology and guide to field trips: New York State Geological Association, 52nd, October 1980, Newark, NJ, Guidebook: Newark, NJ, Rutgers University Newark College of Arts and Sciences, 398 p.

Olsen, P. E., 1984 ms., Size (sic) and shape of the original Newark Basin--historical accident sets the stage for ecosystem development, Chapter 3, p. 184-223 in Comparative paleolimnology of the Newark Supergroup--A study of ecosystem evolution: New Haven, CT, Yale University Department of Biological Sciences, Ph. D. Dissertation, 726 p.

Olsen, P. E., 1984, Periodicity of lake-level cycles in the Late Triassic Lockatong Formation of the Newark basin (Newark Supergroup, New Jersey and Pennsylvania, p. 129-146 in Berger, Andre; Imbrie, John; Hays, J.; Kukla, George; and Salzman, Barry, eds., Milankovitch and climate, NATO Symposium: Dordrecht, Holland, D.Reidel Publishing Company, part 1.

Olsen, P. E., 1986, A 40-million year (sic) lake record of orbital climatic forcing: Science, v. 234, p. 842-847.

Olsen, P. E., 1988a, Continuity of strata in the Newark and Hartford basins, p. 6-18 in Froelich, A. J., and Robinson, G. R., Jr., eds., Studies of the early Mesozoic basins of the eastern United States: U. S. Geological Survey Bulletin 1776, 423 p.

Olsen, P. E., 1988b, Paleontology (sic) and paleoecology of the Newark Supergroup (Early Mesozoic, eastern North America), Chapter 8 in Manspeizer, Warren, ed., Triassic-Jurassic rifting, continental breakup and the origin of the Atlantic Ocean and passive margin: Amsterdam, The Netherlands, Elsevier Science Publishers, 998 p. (2 volumes).

Olsen, P. E., McCune, A. R., and Thomson, K. S., 1982, Correlation of the Early (sic) Mesozoic Newark Supergroup by vertebrates, principally fishes: American Journal of Science, v. 282, p. 1-44.

Olsson, R. K., 1980, The New Jersey coastal plain and its relationship with the Baltimore Canyon trough, p. 112-129 in Manspeizer, Warren, ed., Field studies in New Jersey geology and guide to field trips: New York State Geological Association, Annual Meeting, 52nd, October 1980, Newark, New Jersey, Guidebook: Newark, NJ, Rutgers University Newark College of Arts and Sciences, Department of Geology, 398 p.

Opdyke, N. D., 1961, The paleomagnetism of the New Jersey Triassic; a field study of the inclination error in red sediments: Journal of Geophysical Research, v. 66, p. 1941-1949.

Oshchudlak, M. E., and Hubert, J. F., 1988, Petrology of Mesozoic sandstones in the Newark basin, central New Jersey and adjacent New York, Chapter 13 in Manspeizer, Warren, ed., Triassic-Jurassic rifting, continental breakup and the origin of the Atlantic Ocean and passive margin: Amsterdam, The Netherlands, Elsevier Science Publishers, 998 p. (2 volumes).

Parker, R. A., Houghton, H. F., and McDowell, R. C., 1988, Stratigraphic framework and distribution of early (sic) Mesozoic rocks of the northern Newark basin, New Jersey and New York, p. 31-39 in Froelich, A. J.; and Robinson, G. R., Jr., eds., Studies of the Early Mesozoic basins of the eastern United States: U. S. Geological Survey Bulletin 1776, 423 p.

Percival, J. G., 1842, Report on the geology of the state of Connecticut: New Haven, CT, Osborn and Baldwin, 495 p.

Petersen, T. A.; Brown, L. A.; Cook, F. A.; Kaufman, Sidney; and Oliver, J. A., 1984, Structure of the Riddleville basin from COCORP seismic data and implications for reactivation tectonics: Journal of Geology, v. 92, no. 3, p. 261-271.

Phillips, J. D., 1988, A geophysical study of the northern Hartford basin and vicinity, Massachusetts, p. 235-247 in Froelich, A. J.; and Robinson, G. R., Jr., eds., Studies of the Early Mesozoic basins of the eastern United States: U. S. Geological Survey Bulletin 1776, 423 p.

Phillips, J. D., and Forsythe, D. W., 1972, Plate tectonics, paleomagnetism, and the opening of the Atlantic: Geological Society of America Bulletin, v. 83, p. 1579-1600.

Philpotts, A. R., 1985, Recent petrologic studies of Mesozoic igneous rocks in Connecticut, p. 107-110 in Robinson, G. R., Jr.; and Froelich, A. J., eds., U. S. Geological Survey workshop on the Early Mesozoic basins of the eastern United States, Second, Proceedings: U. S. Geological Survey Circular 946, 147 p.

Philpotts, A. R., and Burkett, D. H., 1985, Mesozoic diabases from west-central New Jersey: a discussion: Northeastern Geology, v. 6, p. 47-49.

Philpotts, A. R.; and Reichenbach, Ingrid, 1985, Differentiation of Mesozoic basalts of the Hartford basin, Connecticut: Geological Society of America Bulletin, v. 96, no. 9, p. 1131-1139.

Pirsson, L. V.; and Schuchert, Charles, 1915, A textbook of geology: New York, NY, John Wiley and Sons, 1051 p.

Pitman, W. C., III; and Talwani, Manik, Sea-floor spreading in the North Atlantic: Geological Society of America Bulletin, v. 83, p. 619-646.

Pratt, L. M., and Burruss, R. C., 1988, Evidence for petroleum generation (sic) and migration in the Hartford and Newark basins, p. 74-79 in Froelich, A. J.; and Robinson, G. R., Jr., eds., Studies of the Early Mesozoic basins of the eastern United States: U. S. Geological Survey Bulletin 1776, 423 p.

Pratt, L. M., Shaw, C. A., and Burruss, R. C., 1988, Thermal histories of the Hartford and Newark basins inferred from maturation indices of organic matter, p. 48-62 in Froelich, A. J.; and Robinson, G. R., Jr., eds, Studies of the Early Mesozoic basins of the eastern United States: U. S. Geological Survey Bulletin 1776, 423 p.

Puffer, J. H., 1987, The Palisades Sill and Watchung basalt flows, northern New Jersey, p. 91-96 in Roy, D. C., ed., Northeastern Section of the Geological Society of America, Centennial Fieldguide, Volume 5, 481 p.

Puffer, J. H., 1988, The Watchung Basalts revisited, p. 83-105 in Husch, J. M., and Hozik, M. J., eds., Geology of the central Newark basin, field guide and proceedings: Geological Association of New Jersey, 5th Annual Meeting: Lawrenceville, New Jersey, Rider College, xxx p.

Puffer, J. H., Geiger, F. J., and Camanno, E. J., 1982, Mesozoic igneous rocks of Rockland County, New York: Northeastern Geology, v. 4, no. 3/4, p. 121-130.

Puffer, J. H.; Hurtubise, D. O.; Geiger, F. J.; and Lechler, Paul, 1981a, Chemical composition and stratigraphic correlation of the Mesozoic basalt units of the Newark Basin, New Jersey, and the Hartford Basin, Connecticut: Summary: Geological Society of America Bulletin, v. 92, Part I, no. 4, p. 155-159.

Puffer, J. H.; Hurtubise, D. O.; Geiger, F. J.; and Lechler, Paul, 1981b, Chemical composition and stratigraphic correlation of the Mesozoic basalt units of the Newark Basin, New Jersey, and the Hartford Basin, Connecticut: Geological Society of America Bulletin, v. 92, Part II, no. 4, p. 515-553.

Puffer, J. H., Husch, J. M., and Benimoff, A. I., 1992, The Palisades Sill and Watchung basalt flows, northern New Jersey and southeastern New York: a geological summary and field guide: New Jersey Geological Survey, Open-file Report OFR 92-1, 27 p.

Puffer, J. H., and Lechler, P., 1979, The geochemistry of Cushetunk Mountain, New Jersey: New Jersey Academy of Sciences Bulletin, v. 24, p. 1-5.

Puffer, J. H., and Lechler, P., 1980, Geochemical cross sections through the Watchung Basalt of New Jersey: Geological Society of America Bulletin, Part I, v. 91, p. 7-10; Part II, p. 156-191.

Puffer, J. H., and Philpotts, A. R., 1988, Eastern North American quartz tholeites: geochemistry and petrology, Chapter 24 in Manspeizer, Warren, ed., Triassic-Jurassic rifting, continental breakup and the origin of the Atlantic Ocean and passive margin: Amsterdam, The Netherlands, Elsevier Science Publishers, 998 p. (2 volumes).

Raisz, E. J., 1930, Physiographic diagram of the New York region: Maplewood, NJ, The Geographic Press, Hammond Map Co.

Rankin, D. W., 1976, Appalachian salients and recesses: Late Precambrian continental breakup and the opening of the Iapetus Ocean: Journal of Geophysical Research, v. 81, no. 32, p. 5605-5619.

Ratcliffe, N. M., 1971, The Ramapo fault system in New York and adjacent New Jersey--a case of tectonic heredity: Geological Society of America Bulletin, v. 82, p. 125-141.

Ratcliffe, N. M., 1980, Brittle faults (Ramapo Fault) and phyllonitic ductile shear zones in the basement rocks of the Ramapo seismic zones New York and New Jersey, and their relationship to current seismicity, p. 278-311 in Manspeizer, Warren, ed., Field studies in New Jersey geology and guide to field trips: New York State Geological Association, 52nd, October 1980, Newark, New Jerseu, Guidebook: Newark, NJ, Rutgers University Newark College of Arts and Sciences, 398 p.

Ratcliffe, N. M., 1988, Reinterpretation of the relationship of the western extension of the Palisade sill to the lava flows (sic) at Ladentown, New York, based on new core data, p. 113-135 in Froelich, A. J.; and Robinson, G. R., Jr., eds., 1988, Studies of the early Mesozoic basins of the eastern United States: U. S. Geological Survey Bulletin 1776, 423 p.

Ratcliffe, N. M., and Burton, W. C., 1988, Structural analysis of the Furlong fault and the relation (sic) of mineralization (sic) to faulting and diabase intrusion, Newark basin, Pennsylvania, p. 176-193 in Froelich, A.J., and Robinson, G. R., Jr., eds., 1988, Studies of the early Mesozoic basins of the eastern United States: U. S. Geological Survey Bulletin 1776, 423 p.

Ratcliffe. N. M., Burton, W. C., D'Angelo, R. M., and Costain, J. K., 1986, Low-angle extensional faulting, reactivated mylonites, and seismic reflection (sic) geometry of the Newark basin margin in eastern Pennsylvania: Geology, v. 14, p. 766-770.

Redfield, W. C., 1843, Notice of newly discovered fish beds and a fossil foot mark in the Red Sandstone formation of New Jersey: American Journal of Science, series, v. 43, p. 134-1326.

Redfield, W. C., 1856, On the relations (sic) of the fossil fishes of the sandstone of Connecticut and other Atlantic states to the Liassic and Oolitic periods: American Journal of Science, 2nd series, v. 22, p. 357-363.

Redfield, W. C., 1857, On the relations (sic) of the fossil fishes of the sandstone of Connecticut and other Atlantic states, to the Liassic and Jurassic periods: American Association for the Advancement of Science Proceedings, v. 10, part. 2, p. 180-188.

Ressetar, R. M., 1976 ms., Major (sic) and minor element (sic) geochemistry of the Holyoke Basalt, Connecticut Triassic Basin: Columbia, SC, University of South Carolina Department of Geology Master's Thesis, 62 p.

Roberts, Alan; and Yielding, Graham, 1994, Continental extensional tectonics, Ch. 11, p. 223-250 in Hancock, P. L., ed., Continental deformation: Oxford-New York-Seoul-Tokyo, Pergamon Press, 421 p.

Rodgers, D. A., 1980, Analysis of pull-apart basin (sic) development produced by en ,chelon (sic) and strike-slip faults, p. 27-41 in Ballance, P. F.; and Reading, H. G., eds., Sedimentation in oblique-slip mobile zones: International Association of Sedimentologists Special Publication No. 4, xxx p.

Rogers, H. D., 1839, Middle Secondary Red Sandstone formation, p. 19-23 in Pennsylvania State Geological Survey Annual Report, 3rd: Harrisburg, 119 p.

Rogers, H. D., 1840, Description of the geology of the State of New Jersey, being a final report: Philadelphia, PA, C. Sherman and Company, 301 p.

Rogers, H. D., 1842, [Remarks on a paper by Edward Hitchcock]: American Journal of Science, series, v. 43, p. 170.

Rogers, H. D., 1854, [On the inclination and thickness of the sandstone of the Connecticut Valley, remarks on a paper by Edward Hitchcock]: Boston Society of Natural History Proceedings, v. 4, p. 379-380.

Rogers, H. D., 1858, Geology of Pennsylvania. A government survey with a general view of the geology of the United States, essays on the Coal-Formation and its fossils, and a description of the coal-fields of North America and Great Britain: Edinburgh and London, W. Blackwood and Sons; Philadelphia, PA, J. Lippincott and Company, in Two Volumes, v. 2, part 2, p. 667-1045.

Rogers, H. D., 1865, Description of the geology of the State of New Jersey, being a final report: Trenton, NJ, J. R. Freese, "State Gazette" Office, 227 p.

Rogers, W. B., 1842, [On the prevailing dip in the various areas of New Red Sandstone of the Atlantic slope, remarks on a paper by Edward Hitchcock]: American Journal of Science, 1st series, v. 43, p. 171-172.

Rogers, W. B., 1860, [On the stratigraphic relations (sic) of deposits formed in an ocean under conditions of stationary (sic), subsiding (sic), and rising position of the sea bottom]: Boston Society of Natural History Proceedings, v. 7, p. 246-249, 273-275.

Rosendahl, B. R., 1987, Architecture of continental rifts with special reference to East Africa: Annual Reviews of Earth and Planetary Sciences, v. 15, p. 445-503.

Rosendahl, B. R., and Livingstone, D. A., 1983, Rift lakes of East Africa: New seismic data and implications for future research: Episodes, v. 6, no. 1, p. 14-19.

Rosendahl, B. R.; Reynolds, D. J.; Lonben, P. M.; Burgess, C. F.; McGill, J.; Scott, D.; Lambiase, J. J.; and Derksen, S. J., 1986, Structural expressions of rifting: Lessons from Lake Tanganyika, p. 27-38 in Frostick, L. E.; Renaut, R. W.; Reid, Ian; and Tiercelin, J. T., eds., Sedimentation in the African rifts: Geological Society of London Special Publication No. 25, 381 p.

Russell, I. C., 1877, On the intrusive nature of the Triassic trap sheets of New Jersey: American Journal of Science, 3rd series, v. 15, p. 277-280.

Russell, I. C., 1878, On the physical history of the Triassic formation in New Jersey and the Connecticut valley: New York Academy of Sciences Annals, v. 1 (1879), p. 220-254.

Russell, I. C., 1880, On the former extent of the Triassic formation of the Atlantic states: American Naturalist, v. 14, p. 703-712.

Russell, I. C., 1892, Correlation papers. The Newark System: U. S. Geological Survey Bulletin 85, 344 p.

Russell, W. L., 1922, The structural and stratigraphic relations (sic) of the Great Triassic fault of southern Connecticut: American Journal of Science, 5th series, v. 4, p. 483-497.

Sanders, J. E., 1958, Stratigraphy and structure of the Triassic rocks of central Connecticut: New England Intercollegiate Geological Field Conference, Annual Meeting, 50th, Guidebook for Trip B, 13 p. (mimeographed).

Sanders, J. E., 1960, Structural history of Triassic rocks of Connecticut Valley belt and its regional implications: New York Academy of Sciences Transactions, Series II, v. 23, p. 119-132.

Sanders, J. E., 1962a, Strike-slip displacement on faults in Triassic rocks in New Jersey: Science, v. 136, p. 40-42.

Sanders, J. E., 1962b, Stratigraphy of the Talcott Formation (Upper Triassic), southern Connecticut (abstract): Geological Society of America Special Papers No. 68, p. 260 (only).

Sanders, J. E., 1962c, Relationship of folds to faults in Upper Triassic rocks northeast of the Schuylkill (Pennsylvania to Massachusetts) (abstract): Geological Society of America Special Papers No. 68, p. 260-261.

Sanders, J. E., 1963, Late Triassic tectonic history of north-eastern United States: American Journal of Science, v. 261, p. 501-524.

Sanders, J. E., 1968, Stratigraphy (sic) and primary sedimentary structures of fine-grained, well-bedded strata, inferred lake deposits, Upper Triassic, central and southern Connecticut, p. 265-305 in Klein, G. deV., ed., Late Paleozoic and Mesozoic continental sedimentation, northeastern North America: Geological Society of America Special Paper 106, 315 p.

Sanders, J. E., 1970, Stratigraphy (sic) and structure of the Triassic strata of the Gaillard graben, south-central Connecticut: Connecticut Geological and Natural History Survey Guidebook No. 3, 15 p.

Sanders, J. E., 1971, Triassic rocks, northeastern North America: regional tectonic significance in light of plate tectonics (extended abstract): Geological Society of America Abstracts With Programs, v. 3, no. 7, p. 781-783.

Sanders, J. E., 1974a, Geomorphology of the Hudson Estuary, p. 5-38 in Roels, Oswald, ed., Hudson River colloquium: New York Academy of Sciences Annals, v. 250, 185 p.

Sanders, J. E., 1974b, Guidebook to field trip in Rockland County, New York: New York, NY, Petroleum Exploration Society of New York, 87 p.

Sanders, J. E., 1978, Primary sedimentary structures, p. 680-682 in Fairbridge, R. W.; and Bourgeois, Joanne, eds., The encyclopedia of sedimentology: Encyclopedia of Earth Sciences, v. VI: Stroudsburg, PA, Dowden, Hutchinson, and Ross, 901 p.

Sanders, J. E., 1981, Principles of physical geology: New York, NY, John Wiley and Sons, 624 p.

Sanders, J. E., 1994c, Newark basin-filling strata and associated mafic igneous rocks, p. 201-212 in Benimoff, A. I., ed., The geology of Staten Island, New York: Geological Association of New Jersey Annual Meeting, 11th, Somerset, NJ, 14-15 October 1994, Field guide and proceedings, 296 p.

Sanders, J. E., 1994d, Coastal-plain sands and clays of Late Cretaceous age, p. 213-216 in Benimoff, A. I., ed., The geology of Staten Island, New York: Geological Association of New Jersey Annual Meeting, 11th, Somerset, NJ, 14-15 October 1994, Field guide and proceedings, 296 p.

Sanders, J. E., Friedman, G. M., and Sternbach, C. A., 1981, Extinct (sic) and active continental margin (sic) deposits and their tectonic-switchover products: Appalachian orogen ("Eastern Overthrust Belt")-Catskill Plateau-Newark basin-Atlantic coastal plain, p. 104-232 in Hobbs, G. W., ed., Field guide to the geology of the Paleozoic, Mesozoic, and Tertiary rocks of New Jersey and the central Hudson valley: New York, NY, Petroleum Exploration Society of New York, 232 p.

Sanders, J. E., Guidotti, C. V., and Wilde, Pat, 1963, Foxon fault and Gaillard graben in the Triassic of southern Connecticut: Connecticut Geological and Natural History Survey Report of Investigations No. 2, 16 p.

Sanders, J. E.; and Merguerian, Charles, 1991a, Pleistocene tills in the New York City region: New evidence confirms multiple (three and possibly four) glaciations from two directions (NNE to SSE (sic) and NW to SE) (abstract): Geological Society of America Abstracts with Programs, v. 23, no. 1, p. 123 (only).

Sanders, J. E.; and Merguerian, Charles, 1991b, Pleistocene geology of Long Island's north shore: Sands Point and Garvies Point to Target Rock: Long Island Geologists' Association Field Trip 29 June 1991 Guidebook: Hempstead, NY, Hofstra University Department of Geology, 40 p.

Sanders, J. E.; and Merguerian, Charles, 1992, Directional history of Pleistocene glaciers inferred from features eroded on bedrock, New York metropolitan area, SE NY (abstract): Geological Society of America Abstracts with Programs, v. 24, no. 1, p. 72 (only).

Sanders, J. E.; and Merguerian, Charles, 1994a, Fitting newly discovered north-shore Gilbert-type lacustrine deltas into a revised Pleistocene chronology of Long Island (extended abstract), p. 103-113 in Hanson, G. N., chm., Geology of Long Island and metropolitan New York, 23 April 1994, Stony Brook, NY: Stony Brook, NY, Long Island Geologists Program with Abstracts, 165 p.

Sanders, J. E.; and Merguerian, Charles, 1994b, Glacial geology of the New York City region, p. 93-200 in Benimoff, A. I., ed., The geology of Staten Island, New York: Geological Association of New Jersey Annual Meeting, 11th, Somerset, NJ, 14-15 October 1994, Field guide and proceedings, 296 p.

Sanders, J. E. and Merguerian, Charles, 1995, Evidence for pre-Woodfordian ages of Long Island's terminal moraines (extended abstract), p. 91-106 in Hanson, G. N., chm., Geology of Long Island and metropolitan New York, 22 April 1995, Stony Brook, NY: Stony Brook, NY, Long Island Geologists Program with Abstracts, 135 p.

Sanders, J. E., and Rampino, M. R., 1978, Wisconsinan stratigraphy, New York metropolitan area: interpretation of newly recognized units does not support modern concepts of the "Laurentide" ice sheet (abstract): Geological Society of America Abstracts with Programs, v. 10, no. 2, p. 84 (only).

Savage, E. L., 1968, Trip C: The Triassic rocks of the northern Newark Basin, p. 49-100 in Finks, R. M., ed., New York State Geological Association Annual Meeting, 40th, Queens College, Guidebook: Flushing, NY, Queens College Department of Geology, 253 p.

Sawyer, D. S., 1985, Brittle fracture in the upper mantle during extension of continental lithosphere: Journal of Geophysical Research, v. 90, p. 3021-3025.

Schaller, W. T., 1932, The crystal cavities of the New Jersey zeolite region: U. S. Geological Survey Bulletin 832, 90 p.

Schlische, R. W., 1995, Rift basin (sic) inversion around the margins of the North Atlantic Ocean: Chronology, causes, and consequences (abstract): Geological Society of America Abstracts with Programs, v. 27, no. 1, p. 80 (only).

Schneider, E. D., 1972, Sedimentary evolution of rifted continental margins, p. 109-118 in Shagam, R.; Hargraves, R. B.; Morgan, W. J.; van Houten, F. B.; Burk, C. A.; Holland, H. D.; and Hollister, L. C., eds., Studies in Earth and space sciences: Geological Society of America Memoir 132, 685 p.

Schuberth, C. J., 1968, The geology of New York City and environs: Garden City, NY, Natural History Press, 304 p.

Sclater, J. G., and Francheteau, J., 1970, The implications of terrestrial heat flow (sic) observations on current tectonic (sic) and geochemical models of the crust (sic) and upper mantle of the Earth: Royal Astronomical Society Geophysical Journal, v. 20, p. 509-542.

Seidemann, D. E., 1989, Age of the Triassic/Jurassic boundary a view from the Hartford basin: American Journal of Science, v. 289, p. 553-562.

Seidemann, D. E., Masterson, W. D., Dowling, M. P., and Turekian, K. K., 1984, K-Ar dates and 40Ar/39Ar age spectra for Mesozoic basalt flows of the Hartford Basin, Connecticut and the Newark Basin, New Jersey: Geological Society of America Bulletin, v. 95, p. 594-598.

Sharp, H.S., 1929, A pre-Newark peneplane and its bearing on the origin of the lower Hudson River: American Journal of Science, v. 218, p. 509-518.

Sheridan, R. E., 1976, Sedimentary basins of the Atlantic margin of North America, p. 113-132 in Bott, M. H. P., ed., Sedimentary basins of the continental margin and craton: Inter-Union Commission on Geodynamics Symposium, Durham University, England, 05-09 April 1976, Proceedings: Tectonophysics, v. 36, nos. 1-3 (special issue), 314 p.

Sheriden, R. E., 1969, Subsidence of continental margins: Tectonophysics, v. 7, p. 219.

Shirley, D. N., 1985, Differentiation of the Palisades sill (abstract): Geological Society of America Abstracts With Programs, v. 17, no. 7, p. 716 (only).

Shirley, D. N., 1987, Differentiation and compaction in the Palisades sill: Journal of Petrology, v. 28, p. 835-865.

Shirley, D. N., 1988, Effects of postcumulus fractionation in the Palisades sheet: further evidence from Weehawken, New Jersey, p. 135-141 in Froelich, A. J.; and Robinson, G. R., Jr., eds., Studies of the Early Mesozoic basins of the eastern United States: U. S. Geological Survey Bulletin 1776, 423 p.

Sichko, M. J., Jr., 1970 ms., Structural (sic) and petrological study of the Second Watchung basaltic flow near Pluckemin, New Jersey: Brooklyn, NY, Brooklyn College Department of Geology Master's Thesis, 80 p.

Sleep, N. H., 1971, Thermal effects of the formation of Atlantic continental margins by continental breakup: Royal Astronomical Society Geophysical Journal, v. 24, p. 325-350.

Sloss, L. L., 1963, Sequences in the cratonic interior of North America: Geological Society of America Bulletin, v. 74, no. 2, p. 93-114.

Sloss, L. L., 1964, Tectonic cycles of the North American craton, p. 449-460 in Merriam, D. F., ed., Symposium on cyclic sedimentation: Kansas Geological Survey Bulletin 169, 2 vols. (v. 1, p. 1-380; v. 2, p. 381-636).

Smith, R. C., II; and Rose, A. W., 1970, The occurrence (sic) and chemical composition of two distinct types of Triassic diabase in Pennsylvania (abstract): Geological Society of America Abstracts With Programs, v. 2, no. 7, p. 688 (only).

Smith, R. C., II; Rose, A. W.; and Lanning, R. M., 1975, Geology (sic) and geochemistry of Triassic diabase in Pennsylvania: Geological Society of America Bulletin, v. 86, p. 943-955.

Smith, T. E., 1976, Paleomagnetic study of Lower Mesozoic diabase dikes and sills of Connecticut and Maryland: Canadian Journal of Earth Sciences, v. 13, p. 597-609.

Smith, T. E., and Noltimier, H. C., 1979, Paleomagnetism of the Newark trend (sic) igneous rocks of the north central (sic) Appalachians and the opening of the central Atlantic Ocean: American Journal of Science, v. 279, p. 779-817.

Smoot, J. P., 1985, The closed-basin hypothesis and its use in facies analysis of the Newark Supergroup. Chapter 2, p. 4-10 in Robinson, G. R.; and Froelich, A. J., eds., U. S. Geological Survey workshop on the Early Mesozoic basins of the eastern United States, Second, Proceedings: U. S. Geological Survey Circular 946, 147 p.

Smoot, J. P., and Olsen, P. E., 1988, Massive mudstones in basin analysis and paleoclimate interpretation of the Newark Supergroup, Chapter 10 in Manspeizer, Warren, ed., Triassic-Jurassic rifting, continental breakup and the origin of the Atlantic Ocean and passive margin: Amsterdam, The Netherlands, Elsevier Science Publishers, 998 p. (2 volumes).

Smoot, J. P., and Robinson, G. R., Jr., 1988, Sedimentology of stratabound base-metal occurrences in the Newark Supergroup, p. 356-376 in Froelich, A. J.; and Robinson, G. R., Jr., eds., Studies of the Early Mesozoic basins of the eastern United States: U. S. Geological Survey Bulletin 1776, 423 p.

Spiker, E. C., Kotra, R. K., Hatcher, P. G., Gottfried, R. M., Horan, M. F., and Olsen, P. E., 1988, Source of kerogen in black shales from the Hartford and Newark basins, eastern United States, p. 63-68 in Froelich, A. J.; and Robinson, G. R., Jr., eds., Studies of the Early Mesozoic basins of the eastern United States: U. S. Geological Survey Bulletin 1776, 423 p.

Spry, Alan, 1962, The origin of columnar jointing (sic), particularly in basalt flows (sic): Geological Society of Australia, v. 8, p. 191-216.

Sumner, J. R., 1978, Geophysical investigation of the structural framework of the Newark-Gettysburg Triassic basin, Pennsylvania: Geological Society of America Bulletin, v. 88, p. 935-942.

Sutter, J. F., and Smith, 1979, 40Ar/39Ar ages of diabase intrusions from Newark trend basins in Connecticut and Maryland: initiation of central Atlantic rifting: American Journal of Science, v. 279, p. 808-831.

Taylor, K. C., and 9 others, 1993, Electrical conductivity (sic) measurements from the GISP2 and GRIP Greenland ice cores: Nature, v. 366, p. 549-552.

Thomas, W. A., 1988, Early Mesozoic faults of the northern Gulf Coastal Plain in the context of opening of the Atlantic Ocean, Chapter 19 in Manspeizer, Warren, ed., Triassic-Jurassic rifting, continental breakup and the origin of the Atlantic Ocean and passive margin: Amsterdam, The Netherlands, Elsevier Science Publishers, 998 p. (2 volumes).

Thompson, H. D., 1959, The Palisades Ridge in Rockland County, New York: New York Academy of Sciences Annals, v. 80, p. 1106-1126.

Tomkeieff, S. I., 1940, The basalt lavas (sic) of the Giant's Causeway District of Northern Ireland: Bulletin volcanologique, series 2, v. 6, p. 89-143.

Turner-Peterson, C. E., 1980, Sedimentology (sic) and uranium mineralization in the Triassic-Jurassic Newark basin, Pennsylvania and New Jersey, p. 149-175 in Turner-Peterson, C. E., ed., Uranium in sedimentary rocks-application of the facies concept to exploration: Society of Economic Paleotologists and Mineralogists Rocky Mountain Section Short-course Notes.

Turner-Peterson, C. E., and Smoot, J. P., 1985, New thoughts on facies relationships in the Triassic Stockton and Lockatong formations, Pennsylvania and New Jersey, Chapter 3, p. 10-17 in Robinson, G. R., Jr.; and Froelich, A. J., eds., U. S. Geological Survey workshop on the Early Mesozoic basins of the eastern United States, Second, Proceedings, U. S. Geological Survey Circular 946, 147 p.

Tyrrell, G. W., 1937, Flood basalts and fissure eruption: Bulletin Volcanologique, series 2, no. 1, p. 89-111.

van der Meer, J. J. M., ed., Tills and glaciotectonics: Proc. INQQUA Meeting, Amsterdam, The genesis and lithology of glacial deposits: Rotterdam, A. A. Balkema, xxx p.

Van Houten, F. B., 1960, Composition of Upper Triassic Lockatong Argillite, west-central New Jersey: Journal of Geology, v. 68, no. 6, p. 666-669

Van Houten, F. B., 1962, Cyclic sedimentation and the origin of analcime-rich upper Triassic Lockatong Formation, west-central New Jersey and adjacent Pennsylvania: American Journal of Science, v. 260, p. 561-576.

Van Houten, F. B., 1964, Cyclic lacustrine sedimentation, Upper Triassic Lockatong Formation, central New Jersey and adjacent Pennsylvania, p. 497-531 in Merriam, D. F., ed., Symposium on cyclic sedimentation: Lawrence, KA, University of Kansas, Kansas Geological Survey Bulletin 169, 2 volumes (v. 1, p. 1-380; v. 2, p. 381-636).

Van Houten, F. B., 1965, Composition of Triassic and associated formations of Newark Group, central New Jersey and adjacent Pennsylvania: American Journal of Science, v. 263, p. 825-863.

Van Houten, F. B., 1969, Late (sic) Triassic Newark Group, north-central New Jersey and adjacent Pennsylvania and New York, p. 314-347 in Subitzky, Seymour, ed., Geology of selected areas in New Jersey and eastern Pennsylvania and guidebook of excursions: Geological Society of America, Annual Meeting, Atlantic City 1969: New Brunswick, NJ, Rutgers University Press, 382 p.

Van Houten, F. B., 1977, Triassic-Liassic deposits of Morocco and eastern North America: a comparison: American Association of Petroleum Geologists Bulletin, v. 61, p. 79-99.

Van Houten, F. B., 1980, Late Triassic part of Newark Supergroup, Delaware River section, west-central New Jersey, p. 264-276 in Manspeizer, Warren, ed., Field studies in New Jersey geology and guide to field trips: New York State Geological Association, 52nd, October 1980, Newark, New Jersey, Guidebook: Newark, NJ, Rutgers University Newark College of Arts and Sciences, 398 p.

Venkatakrishnan, R.; and Lutz, R., 1988, A kinematic model for the evolution of Richmond Triassic basin, Virginia, Chapter 18 in Manspeizer, Warren, ed., Triassic-Jurassic rifting, continental breakup and the origin of the Atlantic Ocean and passive margin: Amsterdam, The Netherlands, Elsevier Science Publishers, 998 p. (2 volumes).

Walcott, R. I., 1972, Gravity, flexure, and the growth of sedimentary basins at a continental margin: Geological Society of America Bulletin, v. 83, p. 1845-1848.

Walker, Frederick, 1940, Differentiation of the Palisades diabase: Geological Society of America Bulletin, v. 51, p. 1059-1106.

Walker, K. R., 1969, The Palisades sill, New Jersey: a reinvestigation: Geological Society of America Special Paper 111, 178 p.

Walton, M. S., Jr., and O'Sullivan, R. B., 1950, The intrusive mechanics of a clastic dike: American Journal of Science, v. 248, p. 1-21.

Watts, A. B., 1981, The U. S. Atlantic continental margin: subsidence history, crustal structure and thermal evolution, p. 2-1 to 2-75 in Bally, A. W., ed., Geology of passive continental margins: history, structure,and sedimentologic record (with special emphasis on the Atlantic margins): Tulsa, OK, American Association of Petroleum Geologists Education Course Note Series No. 19.

Watts, A. B., and Ryan, W. B. F., 1976, Flexure of the lithosphere and continental margin (sic) basins, p. 24-44 in Bott, M. H. P., ed., Sedimentary basins of the continental margin and craton: Inter-Union Commission on Geodynamics Symposium, Durham University, England, 05-09 April 1976, Proceedings: Tectonophysics, v. 36, nos. 1-3 (special issue), 314 p.

Weigand, P. W., and Ragland, P. C., 1970, Geochemistry of Mesozoic dolerite dikes from eastern North America: Contributions to Mineralogy and Petrology, v. 29, p. 195-214.

Wernicke, B., 1985, Uniform-sense normal simple shear of the continental lithosphere: Candian Journal of Earth Sciences, v. 22, p. 108-125.

Wernicke, B.; and Burchfiel, B. C., 1982, Modes of extensional tectonics: Journal of Structural Geology, v. 4, p. 105-115.

Wheeler, Girard, 1938, Further evidence of broad-terrane Triassic: Journal of Geomorphology, v. 1, p. 140-142.

Wheeler, Girard, 1939, Triassic fault-line deflections and associated warping: Journal of Geology, v. 47, p. 337-370.

Whelpley, J. D., 1845, [Trap and sandstone of the Connecticut Valley; theory of their relation]: American Association of Geologists and Naturalists Proceedings, 6th meeting, p. 61-64.

White, R. S., 1987, When continents rift: Nature, v. 327, p. 191.

Whitney, J. D., 1860, On the stratigraphic position of the sandstone of the Connecticut Valley: Annals of Scientific Discovery, p. 322.

Whittington, D., 1988, Chemical (sic) and physical constraints on petrogenesis and emplacement of ENA olivine diabase magma types, Chapter 23 in Manspeizer, Warren, ed., Triassic-Jurassic rifting, continental breakup and the origin of the Atlantic Ocean and passive margin: Amsterdam, The Netherlands, Elsevier Science Publishers, 998 p. (2 volumes).

Widmer, Kemble, 1964, The geology (sic) and geography of New Jersey: The New Jersey Historical Series, v. 19: Princeton-New York-Toronto-London, D. Van Nostrand Company, Inc., 193 p.

Willard, Bradford; Freedman, J.; McLaughlin, D. B.; and others, 1959, Geology (sic) and mineral resources of Bucks County, Pennsylvania: Pennsylvania Geological Survey, 4th series, Bulletin C9, 243 p.

Witte, W. K., and Kent, D. V., 1989, A middle Carnian to early Norian (225 Ma) paleopole from sediments of the Newark basin, Pennsylvania: Geological Society of America Bulletin, v. 101, p. 1118-1126.

Wolff, M. P., Sichko, M. J., and Leibling, R. S., 1987, Concepts of physical geology--An illustrated overview: Dubuque, IA, Kendall Hunt Publishing Co., 134 p.

Woodward, H. P., and Drake, C. L., 1963, Appalachian curvature, wrench faulting, and offshore structures: New York Academy of Sciences Transactions, Series II, v. 26, p. 48-63.

Woodworth, J. B., 1932, Contribution to the study of mountain-building (sic): American Journal of Science, 5th series, v. 23, p. 155-171.

Woollard, G. P., 1943, Geologic correlation of areal gravitational and magnetic studies in New Jersey and vicinity: Geological Society of America Bulletin, v. 54, p. 791-818.

Worzel, J. L., and Drake, C. L., 1959, Structure section across the Hudson River at Nyack, N. Y., from seismic observations, p. 1092-1105 in Lowe, K. E., chm. and consulting ed., Modern aspects of the geology of New York City and environs: New York Academy of Sciences Annals, v. 80, art. 4, p. 1047-1169.

Zeigler, P. A., 197, Compressional intra-plate tectonics in the Alpine Foreland: Tectonophysics, v. 137, 420 p.

Zhang, P.; Burchfiel, B. C.; Chen, S.; and Deng, Q., 1989, Extinction of pull-apart basins: Geology, v. 17, p. 814-817.

Filename: 014F Newark Basin Guide 0810.doc